THE UNIVERSITY OF ALBERTA

THE BIOLOGY OF THE LILAC LEAF MINER, *GRACILLARIA SYRINGELLA* FABR. (LEPIDOPTERA:GRACILLARIIDAE)

BY

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A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

OF MASTER OF SCIENCE

DEPARTMENT OF ENTOMOLOGY

EDMONTON, ALBERTA

JUNE, 1966

UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "The Biology of the Lilac Leaf Miner, Gracillaria syringella Fabr. (Lepidoptera : Gracillariidae)" submitted by Florence Marguerite (Rita) Murdoch in partial fulfilment of the requirements for the degree of Master of Science.

ABSTRACT

The life history of Gracillaria syringella Fabr. was followed for the three years of the study, from 1963 to 1965. The habits of the various stages were noted, especially the way in which the larvae mined and rolled the lilac leaves. Population estimates were made in a small area in Calgary. Two ichneumonid parasites were found, Scambus hispae (Harris) and Itoplectis quadricingulata (Provancher). The effects of the lilac leaf miner on its host plant were noted. The world distribution of G. syringella was recorded. Dispersal of the insect in North America from the time of its introduction into this continent, is discussed.

ACKNOWLEDGEMENTS

I should like to express my sincere thanks to Dr. Janet Sharplin, chairman of my examining committee, for her guidance and many valuable suggestions during the supervision of this study. Great appreciation is also extended to the other members of the staff, Entomology Department, University of Alberta, particularly Dr. B. Hocking for critically reading this thesis and for obtaining financial support for this project. Thanks are also due to Mr. J. Packer, Botany Department, for his helpful comments on the contents of the study.

Special thanks to my family, especially my mother, for her great help in making leaf collections and guarding equipment, and to the neighbors in the vicinity of the study area for allowing me to use their lilac bushes.

I wish to thank J.D. Bradley (British Museum of Natural History, London) for identifying G. syringella moths.

I am deeply grateful to E.O. Pearson (Commonwealth Institute of Entomology, British Museum, London) for obtaining distribution records of Gracillaria syringella in Europe. Distribution information from the United States was obtained from the following United States Department of Agriculture, Economic Insect Survey co-ordinators:-

L.M. Burge, Nevada Dept. of Agriculture, Reno, Nevada.

D.M. Coe, Minnesota Dept. of Agriculture, Saint Paul, Minn.

J.G. Conklin, Dept. of Entomology, University of New

Hampshire, Durham, N.H.

D.R. Davis, Smithsonian Institution, United States National Museum, Washington, D.C.

D. Dorward, Survey and Detections Operations, Hyattsville, Maryland.

A.C. Dowdy, Dept. of Entomology, Michigan State University, East Lansing, Mich.

J.G. Franclemont, Dept. of Entomology, New York State College of Agriculture, Cornell University, Ithica, N.Y.

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J.P. Johnson, Connecticut Agricultural Experimental Station, New Haven, Conn.

J.L. Laffoon, Dept. of Entomology and Zoology, Iowa State University, Ames, Iowa.

F.P. Larson, Division of Plant Industry, Oregon Dept. of Agriculture, Salem, Ore.

H.C. Mannis, Dept. of Entomology, University of Idaho, Moscow, Idaho

J.A. Mathewson, Experimental Station, University of Rhode Island, Kingston, R.I.

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H.B. Petty, Illinois Natural History Survey, Urbana, Ill.

R.L. Post, Dept. of Entomology, North Dakota State University, Fargo, N. Dak.

J.W. Scott, Vermont Dept. of Agriculture, Montpelier, Va.

G.S. Simpson, Dept. of Entomology, University of Maine, Orono, Maine.

P.W. Smith, State Dept. of Agriculture, Madison, Wisc.

H.S. Telford, Dept. of Entomology, Washington State University, Pullman, Wash.

H.E. Thompson, Dept. of Entomology, Kansas State University, Manhattan, Kansas.

E.H. Wheeler, Extension Service, University of Massachusetts, Amherst, Mass.

Distribution information from Canada was obtained from the Insect Survey records of the following Canada Department of Forestry, Forest Entomology and Pathology Laboratories:-

Corner Brook, Nfland.	Sault Ste. Marie, Ont.
Frederickton, N.B.	Winnipeg, Man.
Sillery, Quebec.	Calgary, Alta.
Maple, Ont.	Victoria, B.C.

Additional distribution data was obtained from H.W. Goble, Dept. of Zoology, Ontario Agricultural College, Guelph, Ont.

Thanks are also due to various officials of the Canada Department of Agriculture; Dr. C. W. Farstad (Director, Plant Protection Division, Ottawa) and Mr. R. Brandrith (Plant Protection Division, Edmonton) for regulations governing the importation of lilac; C. Copeland (Plant Protection Division, Toronto) for distribution records from Ontario; A.R. Buckley (Plant Research Institute, Ottawa) for information on lilacs grown in the Arboretum at the Central Experimental Farm, Ottawa; Mr. G.S. Walley (Entomology Research Institute, Ottawa) for identification of parasites and Mrs. L.R. Finlayson (Research Institute, Belleville, Ont.) for examining slides of parasite eggs and larvae.

My thanks to A.F. McQuarrie (Canada Department of Transport, Meteorological Branch, Calgary) for the meteorological records of the Calgary area, and to various plant nurserymen in Calgary and Edmonton for information concerning their sources of lilac supply and methods of retailing.

I wish to thank Mr. Robin Leech for identifying spiders and Miss Alise Zaklums, Miss Gisela Buerger and Miss Chriss Norgaard for translating various papers. Appreciation is also due to Mr. Hans Netolinsky for preparation of lilac leaf sections.

I also wish to thank my typist, Miss Jo Turner, for a job well done.

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1. INTRODUCTION

Gracillaria syringella Fabr., the lilac leaf miner, is of European origin and is widely distributed in Europe. It was first recorded from North America in 1923. The lilac leaf miner has become an abundant and widely distributed major pest of lilac (Syringa sp.) through middle North America in the past 40 years. It is not restricted to lilac although this is the most common host in America; privet is also attacked. In Europe G. syringella is found on ash as well as lilac and privet.

In the 19th Century the lilac leaf miner received a great deal of attention. Many superficial reports of the habits of this insect were published. Since 1900 very little has been added to the literature on G. syringella.

The experimental work of this study was carried out in Calgary because the infestation of lilac by the leaf miner was particularily heavy in this area during 1963.

Adults reared from larvae collected in Calgary were sent to the British Museum of Natural History and were identified by J. Bradley as Gracillaria syringella Fabr.

I have attempted a complete biological study of G. syringella, including its life history and habits, parasites and predators, dispersal in Alberta, distribution and spread in North America, and brief notes on control.

2. LITERATURE REVIEW

The lilac leaf miner was first noted in the literature by Réaumur (1737) who gave an account of the leaf rolling habit of the larva and the position of the moth at rest. Fabricius (1794) first described this species under the name of Tinea syringella. Shrank (1798-) employed this same name and noted the habits of the larva. Haworth (1828) described it under the name of Gracillaria anastomosis. Under this designation Curtis (1833) redescribed and figured it, again reporting the habits of the larva. In the same year Bouché (1833) mentioned it under the name of Tinea syringella and Treitschke (1833) described it under the name of Ornix ardeoepennella. Gracillaria syringella was first used by Stephens (1834), later, Zeller (1838), noticing the species mentioned by Réaumur, applied to it the designation Ornix syringella. Duponchel (1838) described it as Gracillaria ardeoepennella but his figure was rather small and badly drawn, hardly recognizable as this species. In 1842 Duponchel again described and figured the leaf miner under the name of Oecophora syringella, expressing surprise that so common an insect had been overlooked by Treitschke, never suspecting that it was identical to ardeoepennella which Treitschke and he himself had described previously. Zeller (1847) emended Stephens' spelling to Gracilaria syringella and this name was retained by Stainton (1851, 1854, 1864). Stainton gave the general characteristics of the genus Gracillaria and described the life histories of 15 species of Gracillaria including the

lilac leaf miner. He described the various life stages of *G. syringella* and remarked that an infestation by the species was very obvious. The geographical distribution and synonymy were also discussed by Stainton. The name *Gracilaria syringella* was also retained by Frey (1856) and Herrich-Schäffer (1853) who made the first recognizable drawings of the insect. Zeller's nomenclature still persists in much of the literature today although it is technically wrong, the spelling *Gracillaria*, given by Haworth (1828), has priority. Goureau (1869) gave a short natural history and description of the moth and the damage it inflicts. Kaltenbach (1874) included the lilac leaf miner in his discussion of plant enemies. He gave a very short life history and reported its occasional appearance on *Euonymus europaeus* in addition to *Syringa vulgaris*, the common lilac; *Ligustrum vulgare*, the common privet and *Fraxinus excelsior*, european ash. Dimmock (1880) described and figured the structure of the head of *G. syringella*. He studied the mouthparts of larval Tinaeina and paid particular attention to the early instars. Dimmock noted that *Gracillaria syringella* was extremely abundant around Leipzig. He contrasted the morphology of the mouthparts of earlier and later instars and correlated the differences with the two different periods of larval development. Fulmek (1910) recognized this progressive metamorphosis in the larva and drew setal pattern diagrams for one instar. Trägårdh (1911, 1913) studied and made general descriptions of the life stages and of the mining habits. He noted the dimorphism of the mouthparts of the larva. He showed that by examining the larvae of different genera it

is possible to trace the gradual modification which has taken place in the shape of their mouthparts that finally resulted in a very specialized head. Trägårdh also showed the relationship between head structure and the larva's living conditions. Collinge (1912) again described the life history and suggested some preventive measures such as picking infested leaves off the shrubs and spraying the shrubs with paraffin emulsion or caustic soda. Truffaut (1912), in addition to giving a short life history, mentioned the presence of three generations per year in France. He also gave a suggestion for control by spraying with a mixture of water, nicotine, alcohol and soap. Sorauer (1913) described the adult, indicating the life cycle and listing some of the host plants. Zacher (1922) studied the life history and found that the lilac leaf miner was attacked by eight species of hymenopterous parasites. He suggested burning infested leaves, trapping adults with a light trap, exposing the pupae in the winter by breaking up the soil surface and spraying the plant with a carbolineum spray to prevent oviposition. Stäger (1923) contributed to the life history information by specifying that oviposition takes place on the leaf surfaces, not on the petioles or leaf-buds as several previous workers had reported. He observed the lilac leaf miner on *Syringa vulgaris*, the common lilac, *S. persica*, the Persian lilac, *Ligustrum vulgare*, the common privet, *Fraxinus excelsior*, european ash and *F. ornatus*. Pussard (1928) contributed to data on the morphology and biology of *G. syringella*. He described all life stages, discussing the embryonic and larval development in detail. He obtained one undetermined

ichneumonid parasite and found sparrows (Ploceidae) and the earwig _Forficula auricularia_, L. to be the most important predators. Määr (1932) made biological observations in Estonia where there were two generations per year. Polezhaev (1941) showed that the number of eggs deposited on a leaf varied directly with the area of the leaf. Ford (1947) conducted tests with 2 to 3.5 percent aqueous solutions of common salt to control mould on the excrement of _G. syringella_ in rolled leaves of privet. The combined emergence of moths and their parasites was increased from less than 20% to 80% by the elimination of the mould. Strokov (1956) gave an account of observations made on _G. syringella_ in Leningrad and Moscow both under laboratory and field conditions. He mentioned eight hymenopterous parasites and that parasitism was heavier in the second generation. Pupae were attacked by _Formica rufa_ L. Several controls were also suggested such as DDT and BHC dusts, 0.05% parathion spray, 1.0% DDT in oil emulsion and 0.25% nicotine sulphate with soap.

The first record of the lilac leaf miner in North America was a short note by Caesar and Ross (1923) reporting the presence of mined lilac leaves from several localities in Ontario. Hutchings (1925) gave a description of the injury to the plant, its economic importance, descriptions of life stages, and control suggestions. He reported the preferential infestation of certain varieties of _Syringa vulgaris_ in the arboretum at the Central Experimental Farm in Ottawa. The discovery of the lilac leaf miner on the west coast by M. J. Forsell is reported by Essig (1926) who also included Forsell's short account

of the larval habits, first mining and then rolling the leaves. Westcott (1946), describing garden insects, included a short life history of *Gracillaria syringella*, giving control suggestions and reporting its occasional presence on members of the genera *Euonymus* and *Deutzia*. Craighead (1950) in "Insect Enemies of Eastern Forests", mentioned the lilac leaf miner and included a short life history, description of life stages. For control he suggested spraying the infested plants with a combined lead arsenate-nicotine sulphate solution before the larvae rolled the leaves. Robert (1957) reported heavy infestations of lilac in Quebec during 1954 and gave specific hatching dates for the second generation of larvae. He mentioned that larvae were unaffected by the first autumn frosts, but that there was considerable mortality later among larvae exposed to frost while in contact with wet leaves. Notes reporting the presence of *G. syringella* in many other localities were found in the literature. (Amyot 1864; Dodge and Rickett 1943; Frey 1856; Herald 1926; Klots 1929; Landgraf 1924; Rept. Dept. Agric (B.C.) 1940-42; Rept. Latvian Central Agric. Soc 1924-25; Rept. Minist. Agric. Canad. 1925-26; Sich 1901; Stary 1938.)

Needham, Frost and Tothill (1928) gave a general account of insect leaf miners including much information on the ecology of leaf miners in North America. In this work is a list of all known North American leaf miners with their host plants. Hering (1951) worked on leaf miners in Europe, providing much the same type of information though in much greater detail. He included comparative biology as well as morphology and discussed mines and mining techniques.

3. GEOGRAPHICAL DISTRIBUTION

3.i. History And Geographical Distribution Of Lilac

Lilacs, in the genus *Syringa* of the Olive family, Oleaceae, are an Old World group of shrubs and small trees confined mainly to Asia and having no indigenous representatives in the New World. There are 28 species of lilac recognized by McKelvey (1928), the most popular ones being the common lilac (*Syringa vulgaris* Linnaeus (1753)) and the Persian lilac (*Syringa persica* Linnaeus).

From evidence collected by McKelvey (1928) on the geographical distribution and history of the common lilac it appears to have originated in the mountains of the Balkan Peninsula. A plant, identified by Lécluse in 1576 as *Syringa vulgaris*, was first mentioned in the literature by Pierre Belon, the French naturalist, in 1554 while he was in Persia. It is not known when the common lilac was first brought into cultivation in Europe, but it was taken, probably to Vienna, from Constantinople, not later than 1563. It was cultivated in Paris in 1601 according to Franchet (1891). From gardens it escaped into the hedge-rows and grew wild. It soon came to be regarded by botanists as indigenous to various countries of western Europe. By 1629 it was cultivated in both the white and purple-colored forms in England.

The Persian lilac is said by McKelvey (1928) to have originated on the mountains of southern Kansu, in central China. From here it was carried to Persia where it became naturalized on the hillslopes and by 1620 it was also known to be in cultivation in Venice. The

Persian lilac is the greatest wanderer of all the species of lilac and it is, with the common lilac, parent of the first hybrid lilac, Syringa chinensis Willd., better known as S. rothomagensis Poiteau & Turpin 1808, which appeared in the Botanical Garden at Rouen, France about 1777.

Various species of lilac are now found all over the temperate regions of Europe and Asia, including such islands as Japan and Britain.

The date of introduction of the common lilac to North America is uncertain. While the probability is that it came over with the early settlers, there is no authentic record of it growing here before the last half of the 18th Century. Today it has spread over most of the populated areas of the temperate zone of North America.

3.ii. Geographical Distribution Of Ash And Privet

The other host plants of the lilac leaf miner are less commonly infested. The genera Fraxinus (ash) and Ligustrum (privet) also belong to the Olive family, Oleaceae. Their distribution in the Eastern Hemisphere is very similar to that of lilac through they extend slightly further south into Malaysia. Throughout Canada and the United States ash is common; both it and privet have a greater southern distribution than lilac. Privet extends less far north; in Canada it is only abundant on Vancouver Island and along the Great Lakes and St. Lawrence River.

Lilac leaf miner infestations on Vancouver Island were observed during the autumn of 1964 and were as abundant on privet as they were

on lilac. Infested ash was never observed during the three years of the study and none of the infestation reports I received were from ash. The most common species of ash infested in Europe, Fraxinus excelsior has never been introduced in any quantity into North America, being used only occasionally as an ornamental.

3.iii. History And Geographical Distribution Of Gracillaria syringella Fabr.

The geographical distribution of Gracillaria syringella Fabr. is dependent on the distribution of its host plants, lilac, privet and ash, though it does not occur through the whole host range.

Gracillaria syringella Fabr. was noticed by Reaumur in France in 1736. Lilac had been there for at least 140 years so the leaf miner was possibly present long before Réaumur saw it. Stainton in 1864 remarked that by then the species was very plentiful throughout Europe, in England, France, Germany and Switzerland. Today most other countries of Europe and Asia can be added to this list. Those countries from which there are no records available, such as China, Norway, Belgium, Spain, Portugal, Hungary and the Balkan countries may also have the insect.

As the first accounts of the lilac leaf miner in North America were from four localities; Toronto, Newcastle, Guelph and Ottawa, the insect must have been present at least a year before this (1923), probably several, to have covered such a large portion of southern Ontario. It was reported in 1924 from the Puget Sound area of the State of Washington. From these first incidences the geographical area covered

by the leaf miner rapidly expanded. On the west coast by 1927 it had spread to Vancouver Island where it was reported from Victoria and Sydney. It reached the city of Vancouver in 1928 and the Okanagan Valley by 1941. By 1960 it was established in Calgary, Alberta. In the east its range included Quebec by 1925, New Brunswick by 1938, Nova Scotia by 1939 and Newfoundland by 1943. It also occurs on Prince Edward Island. In the western United States it was reported from Moscow, Idaho in 1939 and in the eastern United States *G. syringella* had reached Mt. Desert Island in Maine by 1932. It was found in Philadelphia, New York in 1928 and was well established in northern Vermont by 1936.

Today the leaf miners' distribution in North America has expanded to include most of the southern half of Canada except for Saskatchewan and Manitoba where there has been only one report, from Winnipeg, 1965 (Fig. 1). Included also is the northern half of the United States except for a strip extending south from Saskatchewan and Manitoba through North Dakota, South Dakota, Nebraska and Kansas.

G. syringella is well established in southern Alberta and has been found as far north as Edmonton. It was found in small numbers in Edmonton during 1963 and during 1965 was present here in infestation proportions. It may be expected to continue spreading northward and eventually reach the northern limit of the host plant, lilac, as it has done in Russia.

The lilac leaf miner appears to have been introduced to both

coasts of North America at approximately the same time. Just how it entered is not known, however, it was probably in the pupal stage in soil around the roots of imported lilac shipments. Prior to the recent (May, 1965) prohibition of the movement of soil on plants from Europe to Canada, evergreen trees were shipped in soil or peatmoss and deciduous trees were usually shipped barerooted, though lilacs, particularly the French hybrids, were often imported in soil balls. Imported lilac today is packed in peatmoss after the leaves have dropped. The soil around the roots is removed so it is unlikely that the leaf miner pupae are transported with nursery stock nowadays.

3.iv. Differential Attack of Host Plant Species by the Lilac Leaf Miner

Not all species of lilac, ash and privet are infested in Europe and those species which are infested are not attacked equally. From various papers a list was compiled of some of the attacked species in Europe. The species were separated into four categories according to their susceptibility to *G. syringella* attack.

Heavily Infested	Lightly Infested
Syringa vulgaris	*Syringa persica*
Syringa pekinensis	*Syringa villosa*
Syringa josikaea Jacq.	*Syringa emodi*
Fraxinus excelsior L.	*Syringa reflexa*
Fraxinus excelsior var. *monophylla*	*Fraxinus rotundifolia* v. *lentiscifolia*
Ligustrum japonicum	*Fraxinus potamophila*

Heavily Infested (cont.)	Lightly infested (cont.)
Ligustrum ovalifolium	_Ligustrum vulgare_
Ligustrum californicum	
	Slightly Infested
Less Heavily Infested	_Fraxinus americana_
Fraxinus excelsior var. _diversifolia_	_Fraxinus pubescens_
	Fraxinus pennsylvanica

The situation in North America is similar except that none of the _Fraxinus_ (ash) species in North America are attacked and _Ligustrum vulgare_ should be placed in the heavily infested category.

C. B. Hutchings (1924), in Canada, made observations in the Arboretum at the Central Experimental Farm, Ottawa where over 150 varieties of _Syringa vulgaris_ were grown. He observed that the lilac leaf miner showed a marked preference for some varieties while avoiding others entirely. He compiled the following list.

Heavily Infested	Very Slightly Infested	Not Infested
Madame J. Morel	Jacques Calot	Dr. Nobbe
Rouge de Marley	Amethyst	Virginite
Purpurea	De Miribel	Rene Jarry Desloges
Madame Moser	Eckenholm	Geheimrath Singlemann
Ruba insignis	Bulgaria	Mickel Buchner
Monument Carnot	Lovaniensis	Alba grandiflora
Mactostachya	Madame Casimir Perier	Negro
Belle de Nancy	Congo	Madame Briot
	Edward Andre	Montgolfier
	W. M. Robinson	Vergissmeinnicht

Lightly Infested

Prinz Notger

Princess Maria

Dr. Linley

Prof. Sargent

Charles X

Volcan

Furst Liechtenstein

Senateur Volland

Auvergne

Renoncule

Charles Joli

Double Blue S. sibirica

Not Infested (cont.)

S. Murillo

Delepin

President Carnot

Compte Horace de Choiseul

Croix de Brahy

Marie Le Graye

Chas. Baltet

Mad. Abel Chatenay

Emilie Lemoine

Obelisque

Versaliensis

4. MATERIALS AND METHODS

Preliminary studies were carried out in both Calgary and Edmonton during the summer of 1963 and the timing of the life cycle in Alberta was determined. *Gracillaria syringella* infestations proved to be much more extensive in Calgary than in Edmonton so further investigations were carried out in Calgary.

The main study area consisted of the lilac bushes located in north-east Calgary (Fig. 3). It was necessary to be close to the outdoor experiments at all hours. Ten lilac bushes of approximately equal size (seven feet high and three feet in diameter) were used for most observations. Three of the bushes, group A, were situated against a fence. They were partially shielded from winds by the houses and trees on either side. One of the bushes, B, was shielded from all except south winds. It was exposed to the sun for the greater part of the day and had the warmth from the house on two sides, consequently the larvae developed more quickly here than on the other bushes. Groups C and D were shaded much of the time by houses on both sides.

In 1964 collections of ten leaves from each of 10 bushes were made every six days during the spring generation and every three days during the second generation. The leaf collections were not random, but both mined and unmined leaves were included in the sample which was taken as follows. Areas were chosen from different sides of the bush; the inner and outer layers, upper and lower sections. The

leaves picked from these areas with eyes closed, were preserved in alcohol and opened the following winter. As it took at least 20 min. to search each mine this could not be done immediately. In preliminary examinations it was noted whether the leaves were mined or rolled; if they were mined, the size of the mines was estimated. The larvae inside were counted and their head capsules collected from the molt skins and measured to estimate the age of the larvae. The dead larvae were counted. Both the live and dead larvae were examined for external and internal parasites. Internal parasites could be seen through the cuticle and were dissected out. All parasites were mounted on microscope slides. The interior of the mine was examined for signs of mould, predators and bird pecks. The patterns of larval frass were also observed.

Temperatures were recorded with a thermograph under the middle bush of group A during the summer of 1964. Since these temperatures differed little from those recorded at the Calgary Municipal Airport, the airport records were used for 1965.

Other lilac bushes in the immediate vicinity were sampled for estimating moth populations and dispersal experiments. Control was attempted with a systemic insecticide, Dimethoate (Cygon), on bushes in two additional areas. One of the areas consisted of all the lilac bushes on two adjacent lots in the north-east part of Calgary and the other bushes were on one lot in south-west Calgary.

Field observations began May 14, 1964 when several moths emerged on a lilac bush away from the main study area but collections

did not begin until May 26 when moths began appearing in the bushes under observation. Collecting continued until October 1, 1964 and observations continued until all the leaves had dropped off on October 23.

Lilac suckers were planted in eight inch, pressed-paper plant pots which were placed in soil-filled seedling flats. Individual cages were placed around each pot. The cages were constructed of two parts: a frame of chicken wire and a sleeve of muslin (Fig. 4). The caged pots were placed in an unshaded enclosure with polythene-covered fences on the south and west sides to protect the plants from very strong winds that threatened their existence, particularly in the early spring. Observations and experiments were attempted here but none developed satisfactorily. The suckers, only planted that spring, did not have many large leaves on them. Moths placed in these cages, survived for one or two days only. Under dry conditions, without food other moths taken at the same time survived longer than this. It could be that the moths were not able to find enough protection from the weather among so few small leaves.

Although the moths were most active during the early morning and in the evening they were easiest to catch then because they appeared to be less sensitive to slight movements of the leaves and shadows as vials were placed over them. Ten-dram plastic vials with snap-caps were used to catch the moths singly or in pairs; in these they could be quickly and accurately sexed without handling. The external genitalia were examined under a binocular microscope (X 12). This

was easier than using the frenula of the wings.

Larvae and eggs were collected by picking leaves off the lilac bushes and opening the mines in them. Larvae were also caught as they spun their silken threads and descended to the ground on them. During pupation aluminum pie pans (8 inch diameter of soil-covered area) filled with soil were kept under the bushes of group A (Fig. 5) and the descending larvae burrowed into the soil and pupated. After dropping had ceased, the pans were put individually into muslin bags to await emergence of the adults. The emerging moths were counted and the pans searched for those larvae and pupae that failed to complete development.

In estimations of moth populations and dispersal experiments there was some difficulty in finding a substance with which to mark the moths that could be readily seen and yet would not hamper their movements. Many colored powders, both dry and in solution, were tried but the most suitable was Fluoroscein-free Acid, (Allied Chemical Corporation, National Aniline Division) which sticks to the body and wing scales. The powder was applied by placing a small amount in a jar with twenty to thirty moths and then gently shaking it. Care was taken not to get too much powder on the moths as they were killed if the layer of powder on them was too thick. In the laboratory, caged moths with Fluoroscein on them lived a normal length of time with no observable ill effects. The dye particles were red and showed up easily with only a cursory inspection of the captured moths.

In the laboratory two methods were used to rear the larvae.

One method consisted of placing the lower end of a twig or small branch with six to ten leaves on it into a small container of water. The top of the water container was then sealed with tape to prevent descending larvae from drowning and to slow evaporation. The container and twig were then put into a larger glass cage covered with muslin (Fig. 6). The other method consisted of placing one leaf on a very moist piece of cotton in such a way that any cut edge, such as the petiole tip, was embedded in the cotton. This was then put on a filter paper which was moistened every other day, in a covered, plastic petri dish. Excessive moisture was avoided as it encouraged mould formation. Pupae were kept both in the petri dishes and in glass jars partially filled with soil. The jar openings were covered with muslin rather than lids to prevent condensation.

Microscope slides were made of all parasite eggs and larvae using methyl blue dissolved in polyvinyl lactophenyl (Esbe Laboratory Supplies) as a stain and mounting agent.

5. Gracillaria syringella Fabr.

5.A. Description Of Stages

5.A.i. Egg

The transparent chorion of the flattened, prolate, spheroid egg has a reticulate surface with slightly raised,pentagonal markings. As the egg develops it becomes opaque and the curled embryo can be clearly seen within. Length measurements were of the order previously obtained by Pussard (1928) - 0.5 mm x 0.2 mm, in France and Määr (1932) - 0.42 mm-0.54 mm x 0.19 mm-0.26 mm, in Estonia (Table 1).

5.A.ii. Larva

There are five larval instars, the first three mine the leaves and the last two roll them. Table 2 contains measurements of the larval instars.

First Instar - A newly hatched larva consists of a head and 13 other segments; 3 thoracic segments and 9 apparent abdominal segments, the 10th being very small. The flattened, wedge-shaped, prognathous head capsule is relatively large. The cuticle is transparent except for the heavily sclerotized mandibles which are light brown. The body contents are also almost transparent, all that can be seen without special lighting is the gut. There are no legs or prolegs but the thoracic segments bulge laterally more than the abdominal segments, aiding locomotion in the mine.

Second Instar - The head of the second instar larva is still wedge-shaped and prognathous. The translucent body is flattened and

similar to that of the first instar (Fig. 7).

Third Instar - In contrast to the first and second instars, the head of the third instar larva is spherical and hypognathous. Hypognathous heads are recorded by Trägårdh (1913) as typical of external feeding larvae but the third instar *G. syringella* larva still feeds in the mine. Silk is secreted from a median spinneret on the labium and is used to pucker the mine walls, producing greater depth for the now cylindrical larva. The body is a light green color due to the chlorophyll present in the gut. There are three pairs of thoracic legs, each leg composed of three short segments terminating in a long claw. There are four pairs of abdominal prolegs on segments 3, 4, 5 and 10. The prolegs have one or two rings of crochets on them; the arrangement of these is described in section 8 .

Fourth Instar - The body of the fourth instar larva is cylindrical and appears green from the color in the gut. The head capsule is light brown, though darker than that found in the third instar. The mouthparts are of the external feeding type but larger and better developed than those of the third instar. The spinneret is larger in proportion to the size of the head capsule than in the third instar probably because a stronger silk is required to roll the leaf around the larva which has now emerged from the mine.

Fifth Instar - The body color of the fifth instar larva changes from green to a yellowish-white as it matures and stops feeding. The body is cylindrical and covered with numerous bristles. Fulmek (1910) constructed a setal map and provided a complete description as

shown in Fig. 8. The head is hypognathous and a medium brown color.

5.A.iii. Pupa

In the laboratory, without soil, the pupa is found inside a white silk, oval cocoon measuring 7 to 10 mm in length. The cocoon, as it is spun naturally under the surface of the soil, becomes covered with soil particles and debris. The pupa is light brown. Its mouthparts, antennae, wings and legs lie flat against the body but are not fused to it, though they are fused to each other. Two pairs of legs are totally fused to the wings while the metathoracic pair extend beyond the wing tips. The galeae extend beyond the first two pairs of folded legs, almost to the wing tips. The antennae lie lengthwise, reaching to the end of the last abdominal segment. The pupa is capable of considerable movement and if disturbed a vigorous reaction may be set up in which its abdomen is bent rapidly from side to side. The pupa has a sharp point at the anterior end which pierces the cocoon as it wriggles all except the last few abdominal segments free of the cocoon before emergence of the adult (Fig. 9).

5.A.iv. Adult

The adult has the characteristics of the genus Gracillaria as described by Forbes (1923). The species syringella is not included in his key. The adult of Gracillaria syringella (Fig. 10) can be readily identified by the color of its anterior wings. They are a variegated mixture of grey, gold and brown with six oblique bands of yellowish-white. The three apical bands are outlined in black. The distance

from wing tip to wing tip with the anterior wings spread varies from 11 mm to 12 mm. The forewings are narrow, the width at the broadest point is 1 mm, almost doubled in the distal half by a fringe of long fine hairs. The posterior wings are shorter, 10 mm spread, and narrower, 0.75 mm. They are almost surrounded by a fringe of long, light grey, very fine hairs. The underside of both pairs of wings is light grey.

The head is covered with long, smooth, somewhat erect scales. The scales are a mixture of white and grey-brown producing a variegated appearance. The maxillary and labial palpi are also a variegated grey; they are large and project upwards in front of the head.(Fig. 11). The galeae form a proboscis 4 mm long which is held curled at rest. The filiform antennae extend to the wing tips when the moth is at rest.

The body is completely covered with grey scales, those on the ventral side being almost white. The abdomen is 3.5 mm to 4.0 mm in length and 1 mm wide.

The legs are also completely covered with scales, those on the middle tibiae are more dense giving them a bushy appearance. On the posterior tibiae there are two pairs of spurs, one pair is one-third of the distance from the proximal end and the other pair is distal in position. The middle tibiae have only the apical pair, the anterior tibiae none. Each pair of spurs is asymmetrical, that spur nearest the body being longer. The femora are greyish-brown, the anterior pair rather darker than the other two pairs. The anterior and middle tibiae are dark brown, the posterior tibiae are paler. The anterior and middle tarsi are whitish with a few brown patches and the posterior tarsi are

whitish-grey, more or less chequered with pale brown patches.

The moths at rest have the thorax elevated by the long legs. The anterior pairs of legs are held widely separated and directed forward. The posterior legs are placed against the sides of the abdomen with the longer inside spurs curving under it.

The genitalia have not been described.

5. B. Life Cycle and Habits

5. B. i. Habits of the Moth

In Calgary lilac leaf miners overwinter as pupae in cocoons at the surface of the soil under debris and up to 1.5 cms below the surface. The depth of the pupae, according to Strokov (1956), varies with the hardness of the soil. In Russia he found pupae up to 5 cms deep in soft soil, 1 cm to 3 cms deep in heavy soil and at the surface in very hard soil. Emergence of adults in the spring from overwintering pupae was first observed in Calgary on the following dates: 19 May 1963, 26 May 1964 and 27 May 1965. Emergence continued in all three years for about 20 days and moths were seen for an average of 33 days. This

TABLE 1

Sizes of Various Stages of <u>Gracillaria syringella</u>

Stage and Part Measured	Number Measured	Mean Size (mm)	Standard Deviation	Range (mm)
Egg width	17	0.22	0.02	0.18 - 0.24
Egg length	76	0.46	0.04	0.36 - 0.52
Pupa length	6	4.87	0.31	4.40 - 5.36
Adult ♂ - body length excluding antennae	10	4.67	0.33	4.17 - 5.17
- apparent length with wings folded	10	5.92	0.26	5.50 - 6.42
Adult ♀ - body length excluding antennae	9	4.83	0.22	4.41 - 5.08
- apparent length with wings folded	9	6.00	0.24	5.75 - 6.50

TABLE 2

Sizes of Larvae of *G. syringella*

Instar	Number Measured	Mean Width (mm)	Range (mm)	Standard Deviation	Number Measured	Mean Length (mm)	Range (mm)	Standard Deviation
1	40	0.18	0.16 - 0.20	0.01	38	0.94	0.44 - 1.36	0.32
2	40	0.26	0.20 - 0.28	0.02	40	1.62	0.88 - 2.20	0.40
3	40	0.35	0.32 - 0.38	0.02	32	2.44	2.08 - 3.60	0.45
4	40	0.54	0.48 - 0.60	0.03	31	4.58	3.12 - 5.72	0.61
5	34	0.76	0.68 - 0.80	0.03	27	5.76	4.40 - 8.00	0.73

contrasts with the situation in Russia from 1937 to 1939 around Moscow and Leningrad. The earliest moths appeared on May 20 and they were last seen flying on June 9 (Strokov, 1956). In France the moths that emerged in the spring of 1928 were observed to fly for 25 days (Pussard, 1928). Strokov (1956) found that females lived from 5 to 7 days. In the laboratory I found newly hatched females lived from 8 to 14 days or an average of 10 ± 2.3 (18) days while males lived from 3 to 5 days or an average of 3 1/2 ± 0.8 (13) days.

Feeding in G. syringella adults has never been reported. In the laboratory flowers and sucrose-water solution on cotton were offered but the moths were never seen to feed although watched for prolonged periods. Other moths (50) given only water on cotton lived just as long. On five occasions an adult was seen to extend the probosces and three had a drop of sticky substance on the tip. The guts of five wild-caught moths were ground up in Benedict's solution and heated. The mixture turned red indicating the presence of sugar. The experiment was repeated with the guts of five laboratory-raised moths that had access to sucrose solution. A positive result was again obtained, suggesting that some of the moths had fed.

5. B. ii. Mating

The newly emerged adults mate at once. Mating takes place on grass blades, tree trunks and branches and on the lower surface of lilac leaves, also on objects such as a nearby fence and leaves of other trees. The moths, following emergence from the soil, were

observed to make their way up to the tips of grass blades where they remained,waving their antennae. If a moth of the opposite sex walked up the same grass blade, it turned around before reaching the first one so that their anal ends made contact and mating occurred. Mating took place in the shade of the bushes or during evening hours rather in direct sun light. In nature I observed copulation to last from a few moments up to at least 25 minutes. Mating was difficult to observe for long in nature because the pairs walked away from the original grass blades, while still in copulation, and were lost to view. In the laboratory copulation was observed to last from 25 minutes up to three hours. Pussard (1928) thought it lasted a minimum of four to five hours while Theobald (1905) reported at least two matings of 12 to 14 hours.

5.B.iii. Oviposition and Fecundity

Strokov (1956) found that newly emerged, laboratory mated females, under laboratory conditions, could lay up to 248 eggs each. Six field-caught females from June 18, 1965 contained from 44 to 160 eggs each, or an average of 94 eggs per female. They may have already oviposited. Muslin bags were placed around branches of growing lilac bushes. The leaves so enclosed were free of eggs. Four newly hatched and laboratory mated females were placed individually in bags. They laid from 135 to 170 eggs each, an average of 155 eggs per female. Twelve female moths field-caught on the first day of emergence in 1964, caged with one male each, in the

laboratory, laid from 53 to 191 eggs each. The mean number of eggs per female was 111. These moths were seen to mate, almost immediately, once each but they could have mated again as the males lived for several days.

A female ready to lay eggs walks about on the lower surface of the leaf, her abdomen in contact with the epidermis. When she has found a suitable oviposition site she lays her elliptical eggs in rows alongside of a vein. Each egg slightly overlaps the one laid before it and each is glued to those on either side. The eggs, being transparent, are not noticeable in their normal position on the leaf in the shade but they can be seen with the naked eye in direct sunlight because the chorion reflects the light. They are usually placed close to a vein, only 4% of the masses found were near the leaf margins. 56% of the masses were placed close to the midvein and the other 40% were placed near the main lateral veins. Määr (1931) working in Estonia obtained similar results:- 50% next to the midvein, 49% by main lateral veins and 1% beside secondary lateral veins. The mean number of eggs per mass is 7 ± 2.9 (100) with a range from 3 to 19. Strokov's (1956) results from Russia were comparable: - 2 to 20 eggs, average between 5 and 6. Pussard (1928) thought that tactile setae on the tip of the female moth's abdomen detect the ridge of the vein and this releases the egg laying reflex, the ridge acting as a guide to the oviposition site. Pussard suggested that oviposition was only initiated by contact with a vein of a certain size, if it was too high, as in an old leaf, the site was bypassed, if it was too low the

site was also bipassed. This mechanism would account for the fact that very young leaves or sites too near the leaf margin are avoided. When eggs were laid in the laboratory on the smooth, glass walls of the cages the rows were irregular or the eggs were in clumps and not as they are along a vein in regularly placed rows.

5.B.iv. Egg Development

The duration of the egg stage under laboratory conditions at a temperature of about 70°F is from 4 to 8 days or an average of 5 1/2 days. Under natural conditions in the spring at a temperature of about 56°F the egg stage lasts from 7 to 17 days, or an average of 7 1/2 days. Pussard (1928), under laboratory temperatures of 59°F, found that the eggs took nine days to hatch.

The percentage of egg hatching is high. From samples of 2,000 eggs observed in the field it was found that during the spring generation, under natural conditions, 84% of the eggs hatched. Under laboratory conditions the percentage of hatching was 91%, from a total of 420 eggs collected during the same generation. The 9% which did not hatch in the laboratory may not have been fertilized. There was never a whole mass of eggs remaining unhatched; only scattered eggs appeared inviable. Unhatched eggs remained transparent and flattened out. Empty egg shells were also transparent and flattened out but had frass trails leading from them. The difference between the laboratory and field results may have been due to predation by unidentified mites which were seen in the field. In laboratory tests,

however, the mites could not be induced to feed on G. syringella eggs. No egg parasites were ever found and none of the unhatched eggs appeared damaged by larger predators. There was no mould observed on the eggs. The reduced hatch in the field is unexplained.

5. B. v. Larval Development

The head of the first instar larva is situated at the end of the egg distal from the vein. The ventral tip of the egg is cut open using the mandibles and the larva chews through the chorion, which touches the epidermis, straight into the lower leaf epidermis without being exposed on the leaf surface. If the larvae hatch from eggs laid on the upper surface of the leaf (0.1% of the eggs), they are able to survive. Oviposition on the lower surface probably evolved because eggs laid here are sheltered and because there is no thick cuticle. The epidermal mine of each newly hatched larva proceeds in a straight line for a short distance. As the eggs of a mass hatch at approximately the same time and all the larvae proceed straight forward, usually all the mines join, producing one common mine for each egg mass. The first instar larvae in this mine feed gregariously in compact clusters around the edge (see Fig. 12), producing a blotch after they have moved obliquely upwards into the palisade parenchyma. The second instar larvae feed solitarily, though still in the common mine, in the palisade. The cylindrical third instar larvae consume the palisade, and parts of the spongy parenchyma, enlarging the mine. The fourth instar larvae leave only the upper and lower epidermis, then eat a hole through the

thin mine wall and come out onto the lower leaf surface. They roll the leaf as described in Section 9ii. The fifth instar larvae live in the rolled leaf before descending to the ground on silken threads.

The larvae on the ground wriggle around until they have reached satisfactory pupation sites where they construct cocoons. In the laboratory it took about 24 hours for them to build a cocoon and another 12 hours for pupation to be completed. When emergence time approaches, a pupa wriggles, pushing on the end of the cocoon until it is pierced by a tooth on the head of the pupa. The pupa is almost free of the cocoon before the moth emerges. Emergence of the moths developing from the eggs laid in the spring was first observed in Calgary on the following dates: July 28 1963, July 27 1964 and August 3 1965. Moths were seen flying during 1963, 1964 and 1965 for 54 days, 50 days and 53 days respectively.

A second or summer generation of G. syringella begins with eggs laid by the spring (first) generation female moths. During the years 1963-1965 the earliest eggs were observed on July 28, July 27 and August 3 respectively. The larvae developing from these eggs pupated on September 1, September 14 and September 5 respectively. The average length of the egg and larval stages in the second generation over the two years of 1964 and 1965 was 42 days. In the same two years the duration of the egg and larval stages for the first generation was 41 days. The pupae remain as such until the following spring (about 37 weeks).

Table 3 gives the duration of the separate larval instars for

the spring (first) generation but these data were not collected for the autumn (second) generation. The first (spring) generation of most mining insects with two generations develops more rapidly than the second (autumn) generation. There are two reasons for this according to Hering (1951). First, during the second generation the temperature is lower. Second, the leaf cells have a higher protein content and are softer at the beginning of the growth period than in the autumn.

TABLE 3

Average Length in Days of each Stage of the Spring Generation

G. syringella in 1964 and 1965

	1964		1965	
Stage	Laboratory	Field	Laboratory	Field
Egg	6	8	5	7
First Instar	2	3	2	5
Second Instar	3	6	2	9
Third Instar	7	15	7	13
Fourth Instar	5	5	3	5
Fifth Instar	4	5	2	3
Pupa	17	20	16	26
Total	44	63	37	68

TABLE 4

Average Development Times for the Egg and Larval Stages of

G. syringella During 1963, 1964 and 1965

	First (Spring) Generation		Second (Autumn) Generation	
Year	Actual Days	Degree Days	Actual Days	Degree Days
1963	48	848	35	769
1964	42	699	49	685
1965	42	717	33	664
$\bar{x}$ =	44	755	39	706

40°F was the threshold temperature used for degree days of development.

Table 4 shows that this tends not to apply to Gracillaria syringella in Calgary. Although the cumulative temperatures in Alberta are higher during the first (spring) generation than during the second (autumn) (Appendix iii), the eggs are not laid on tiny, new leaves. The leaves must reach a minimal length of 35 mm before the moths will oviposit on them. Out of 500 measured leaves ranging in length from 30 mm to 104 mm, no leaves shorter than 35 mm had eggs on them. So the difference in the quality of the food between the two generations may not be great. This is also shown by the fact that the frass pellet size and amount voided is approximately the same in both generations and not as Hering (1951) reported. He found that there are more and larger pellets of frass in the second generation due to the increased hardness of the cells.

40°F was taken as the threshold temperature in Table 4 to calculate degree days of development because this is approximately

correct for most insects active during the summer in Alberta (Hocking, personal communication).

6. HOST PLANT SELECTION

Gracillaria syringella is an oligophagous insect. The mining larva is dependent for its development on the leaves of a plant belonging to one of the three susceptible genera of the family Oleaceae: Syringa, Fraxinus and Ligustrum.

It is also able to develop on Symphoricarpos, the coralberry, as Voigt (1932) noted, but it does not complete development on species of Chionanthus, the fringe tree which is in the Oleaceae. Voigt (1932) also observed it on the Saxifragaceae genus Deutzia but does not say if development was completed or not. Sich (1911) reported it on Phyllyrea media, of the Oleaceae and Kaltenbach (1874) noticed it on Euonymus, an ornamental temperate genus of the Celastraceae. Later, Stager (1923) and Määr (1931) failed to rear the lilac leaf miner on this plant. I observed it on Populus nigra var italica Muench. (Lombardy Poplar) of the Salicaceae though it did not complete development. The accidently infested Lombardy Poplar, found only twice in 1964, were in the immediate vicinity of many lilac bushes. I have observed other plants used as resting places without eggs being laid. An egg may have occasionally been carried by an ovipositing female to another plant.

In Alberta lilac is the main host plant of G. syringella and it receives most attention in this paper.

7. THE LILAC AND ITS LEAF

Lilacs are deciduous shrubs. Their leaves are opposite, petioled, usually ovate in shape, entire and have reticulate venation with three to seven pairs of veins.

Gracillaria syringella is found on the leaves of the lilac, leaving the flowers untouched. The mesophyll of the lilac leaf is well differentiated into palisade and spongy parenchyma. The palisade parenchyma of two rows of closely packed, columnar cells is next to the upper epidermis. It is rich in chlorophyll and is presumably the most nutritious layer. It is mined by the most specialized first and second instar larvae (Fig. 13). The spongy parenchyma of irregularily placed, open spaced cells is beneath the palisade layer. It does not have as much chlorophyll. This lower, more easily penetrated layer is eaten by the later instar larvae. The mesophyll is enclosed in an epidermis that consists of a single layer of thick-walled transparent cells. On the outer surface of the epidermis, particularly on the upper surface, a waxy cuticle is secreted. The leaf is supported by a framework of veins. The midrib or midvein and the other veins contain the vascular system of the plant. Their hard-walled, lignin-containing cells impede the leaf miner.

8. ADAPTATIONS OF LARVAL MORPHOLOGY FOR MINING

The adaptation of the lilac leaf mining larvae to their habitat has resulted in the modification of their body structure. Morphological differences in the larval instars correspond with variations in the habits of the larvae and with the changing environment during their lives.

Generally, external feeding lepidopterous larvae have round, cylindrical bodies, equally wide at both the fore- and hind ends. They may bear a variety of surface structures such as protuberances and bristles. Mining larvae have restricted living space and they have flattened bodies enabling them to live in the confined space of the mine. It has been shown (Hering, 1951) that the flatter the mine, the flatter are the larvae. The very flat first instar larvae are found first in the lower epidermis and later in the palisade parenchyma where they apparently feed on the cell contents. The flattened second instar larvae in the palisade parenchyma also feed on cell contents. These two instars cut open a cell and suck the contents while the later tissue-feeding instars chew up entire cells. The third instar larvae have the cylindrical body form which occupies the whole space between the upper and lower epidermis. In many other mining larvae the thorax becomes heavily sclerotized but sclerotization in G. syringella remains weak, the fore-end of the lilac leaf miner is only slightly thickened, especially the first thoracic segment.

There are great differences between the cell-content feeding

and tissue-feeding instars due primarily to the degree of flattening of the body. The changes occurring in the head region between instars two and three affect the mouthparts, the shape of the head capsule, antennae and eyes.

Mining G. syringella larvae are dorso-ventrally flattened. They must feed on matter lying only in front and to the sides of them.. The prognathous head position is achieved by the elongation of the labium and genae. The head is wedge-shaped and the extended mandibles at the anterior end form a point, making it much easier to penetrate the epidermal cell walls. There are no ecdysial sutures as the head capsule slips off entire, the posterior part being widest. There are only strengthening ridges present at the rear of the head (Fig. 14). The antennae are situated in a protective depression behind the projecting mouthparts. There are two articles. The basal article has a very characteristic form, being slightly club-shaped and bent inwards. It has two papillae and two hairs, one very small and the other long and curved inwards at the top. The upper article is short and has two short, stout terminal bristles and one papilla (Fig. 15). The ocelli are arranged in a marginal line. There are only two larger ocelli present which have moved forward slightly from the normal position for lepidopterous larvae.

In the tissue-feeding third instar the mine is more spacious and the head capsule is hypognathous (Fig. 16). The larvae may eat matter beneath them as well as that lying to the sides and in front of them. The antennae have three distinct articles: the terminal one is forked

at its tip, bearing on one side a conical papilla covered with sense organs and on the other a small tactile seta, with a small hair between them. The second article has one large and two small setae and two conical sensilla. The large median seta is larger than the whole antenna and is curved in the distal one-third. There are no sensilla on the basal article (Fig. 17). The grouping and number of ocelli are normal with six lying behind the mandibles in an irregular semi-circle.

Trägårdh (1913) and Dimmock (1880) wrote very complete descriptions of the modifications that have taken place in the mouthparts and I will only summarize their results. The labrum of the cell-content-feeders has three to four distinct teeth on it used in cutting up the plant tissue. There is a rounded median depression (Fig. 18). The mining larvae move their heads from side to side when eating, thus, from the shape of the labrum it would appear that it is used as a saw. The mandibles are horizontal and extend slightly beyond the labrum. There are two very long, narrow, pointed and closely set teeth on them. The labium is a thin lamina with an incision on the anterior margin. The hypopharynx which has merged with the labium is covered with very fine hairs. There is no spinneret and there are no labial palpi. The labium is flanked on either side by the atrophied maxillae (Fig. 19).

The labrum of the tissue-feeders is plate-like, bilobed and on the edge of the ventral surface are rows of fine hairs. The labrum of the cell-content-feeders is larger than this in comparison with the

size of the head capsule. The mandibles of the tissue-feeders are convex. There are four teeth on the edge of the ventral surface and a fifth lies inside on the ventral surface (Fig. 20). There is a spinneret present on the labium and the maxillae have the form common to lepidopterous larvae.

The modification of the larval trunk consists primarily of changes in the body extremities. The crawling locomotion of lepidopterous larvae is not possible in the confined space of the early mines. The first two instars are legless but other modifications give the larvae a degree of movement in the mine. There are pronounced constrictions between the body segments which bulge laterally, especially in the thorax. There are numerous setae covering the body that also provide some grip on the sides of the mine. The pattern of these setae is taxonomically important as the mining larvae do not have the distinct colors and patterns of the free-living larvae. In the third instar where the depth of the mine is increased, there are both thoracic and abdominal prolegs. The thoracic ones are well developed with one pre-tarsal claw. The abdominal prolegs are on segments 3, 4, 5 and 10. They have crochets arranged in a circle with a semi-circle of crochets inside the posterior part of the circle (Fig. 21). Setae are more numerous and much longer than in the cell-content feeding instars.

9. THE MINE AND THE CHANGES DURING MINING OPERATIONS

9.i. The Mine And Mining Operations

Mining larvae are very selective feeders, avoiding tissues such as the walls of the epidermal cells and the cuticle. They avoid the hard cells of the leaf veins and reach fresh portions of the leaf by crossing the veins towards the margins of the leaf where the veins flatten out.

The food available is largely dependent on the position of the eggs from which the larvae hatch. The egg masses are laid on the lower surface of the leaf next to veins. G. syringella larvae hatch from the eggs and burrow obliquely into the lower epidermis. The larvae remain as cell-content-feeders in the epidermis for part of the first instar, producing liquid excretia. The mine is very short (1 to 4 mm) and is not visible from the upper side of the leaf. From the lower epidermis the larvae again burrow obliquely through the spongy parenchyma into the palisade parenchyma and the mine becomes more apparent from the upper side than the lower. They usually stay in the second layer of palisade though they may venture into the upper row and return. They moult into the second instar and continue to mine the second row of palisade. Fragments of cell walls are consumed and pass through into the frass which becomes increasingly pellet-like though it is still semi-solid. The frass of these first two instars is never found in the feeding area. The larva eats lying on its ventral side with its anus situated towards the center of the mine so

that the mouthparts are at right angles to the mine edge. Frass is, therefore, found a length of the body away from the mine edge. This forms a distinct pattern of frass inside the mine (Fig. 22). After the second moult the cylindrical third instar larvae consume both the palisade and spongy parenchyma enlarging the mine cavity rapidly. As they become tissue feeders the quantity of undigested, excreted matter increases. Hering (1951) reports frass investigations showing many substances in the parenchyma cells eg. some carbohydrates and mineral products; calcium oxalate and calcium carbonate are defecated without being digested. The green chlorophyll granules become darker than living cells after passing through the digestive tract but this is only a secondary change of the chlorophyll to chlorophyllan without the larva deriving any benefit from the process. The frass is now in the form of distinct, moist pellets but the pattern present in the first two instars disappears as the pellets roll freely in the mine. The depth of the mine is increased by the consumption of the upper part of the spongy parenchyma and patches of the first and second rows of palisade. Vaulting begins with the production of silk threads which are fastened at several points to the floor of the mine. These threads contract and the roof of the mine bulges and puckers while troughs form in the floor. Frass collects in the troughs and some sticks to the silk webbing. With the moult to the fourth instar the mine becomes of full depth as all the palisade and spongy parenchyma are consumed. The result is that both mine surfaces are very thin and transparent, consisting of one epidermal cell layer. The mine is equally apparent

from both surfaces. The floor and roof of the mine are both thinner so they bulge more when the silk threads strung between them contract, increasing the depth inside the mine. The depth of the mine now varies from 1 mm to 5 mm. Frass appears in larger pellets, is less moist and rolls freely around the mine. The fourth instar larvae do not stay long in the mine at this stage but eat holes through the lower epidermis and proceed out onto the outer surface of the leaf.

Figure 23 is an upper surface view of a small mine on a lilac leaf showing the differences in coloration in the areas mined by first to fourth instar larvae.

9.ii. The Rolled Leaf

Fourth instar larvae chew channels across the midvein without appearing to consume the cut tissue. The cuts vary in number from one to about ten and they are between 1mm and 10 mm apart. Rolling begins at the apex of the leaf. Silk threads are strung by the larvae from the tip on the underside of the leaf. The threads contract as they dry and the leaf tip rolls under. After these threads have fully contracted, more threads are attached from points across the middle of the roll outside to the unrolled part of the leaf. The threads are 1 mm to 7 mm long when contracted. Some larvae make only a few turns (Fig. 24) while others repeat the process until the entire leaf is rolled. The ends of the roll are flattened when a series of threads strung across the openings contract, closing the apertures (Fig. 25). Frass produced before the roll is completed dries out and drops out of the roll before

the ends are closed. Inside the roll the larvae eat parts of all tissue except the upper epidermis. Since the larvae are usually found first in the center of the roll, all of these layers are eaten at the tip of the leaf which is rolled tightest. This is usually where the fourth instar head capsules are found after the larvae have molted into the fifth instar. The same feeding habits are retained by fifth instar larvae which do not limit themselves to the center of the roll but eat patches throughout. The frass in the roll dries out very quickly, the pellets are loose, collecting in corners and in the webbing. When the larvae are ready to pupate they eat holes through the upper epidermis and proceed onto the outer surface of the roll. From here they descend to the ground on silk threads.

After the leaf rolling stage is reached the larvae are able to move to new, uninjured leaves which are touching their original leaves. The second leaf is tightly joined to the mined leaf with silk. Most of the rolled leaves examined had not been mined, indicating that the larvae had moved onto them in the fourth or fifth instar. 62% were rolled only, 14% were mined only and 24% were both mined and rolled (Fig. 26).

9.iii. External Mine Coloration

The color of the mine emphasizes the details of its shape. It is usually the result of parts being eaten out of the plant tissue. Air penetrates the cavities and dries them out producing a different color from that of the rest of the leaf.

The lower epidermal mine produced by the first instar larvae

leaves a very thin layer of epidermis. It is visible from the lower leaf surface only. In direct light the layer is a transparent yellowish color.

The mine is visible from the upper surface when the first instar larvae reach the palisade parenchyma. It appears light green in direct light, caused by the complete or partial removal of the palisade parenchyma leaving the epidermis undamaged. It is only slightly visible from the lower leaf surface, appearing a darker green due to the presence of the spongy parenchyma.

The third instar larvae produce a mine which is increasingly conspicuous from the lower surface. The spongy parenchyma is partially consumed with the palisade, and the mine appears a lighter green. The full depth mine is equally apparent from both leaf surfaces as a transparent, yellowish area, since only the two epidermal layers remain.

When exit holes are produced by the fourth instar larvae, or when a hole is accidently made in the mine, the interior dries out quickly and turns a dark brown color. The walls shrink, become brittle and crumble easily. This also happens if the larvae die before leaving the mine, even though there are no holes present.

9.iv. Changes In The Infested Leaf

Hering (1951) reports that two factors are responsible for deformities and tears in leaves of lilac, caused by mining insects: the degree of leaf development at the time of oviposition or during mine construction and the position of the mine in relation to the

vascular system. I observed that the lilac leaf was very well developed before oviposition. As the leaf tissue was developed and expanded near the veins before the marginal areas and since the eggs were laid close to the veins, their presence did not stop the expansion of leaf cells. No externally visible abnormalities in leaf development could be detected. The eggs are laid along the edge of a vein, not on or inside one and the mining larvae avoid the vascular bundles so that circulation inside the veins is not interrupted. Bail (1908), in a study of plant malformations and their causes, stated that G. syringella larvae did cause malformations to lilac leaves. He found lobes and indentations that he thought were caused by the larvae eating the leaf, and curved leaves with damage on one margin which he said were due to young larvae eating the leaf buds but not entering them. I did not observe G. syringella larvae in or on leaf buds.

Deformities and tears were noticed, however, in some leaves but generally there were no mines in the deformed area. A species of the fungus genu Phytophthora, was found on lilac in Calgary during the summer of 1965 which caused deformities in a great many leaves. Late spring frosts may also cause localized injory by killing or splitting the tissue in the intervein areas so that later the leaves may appear as if lacerated or torn (Herald, 1926). G. syringella seemed to avoid deformed areas of lilac leaves.

After a mine is abandoned, the thin epidermis above or below the mine is often destroyed. Air dries out the interior of the mine or dampness and rain penetrate inside the mine and produce further

disintegration. Mined areas become brittle and break off in the wind. The unmined areas of the leaf remain green and alive. Abandoned mines are hiding-places to many other insects which have no direct connection with the mines and these can alter the original appearance of the mine and the leaf.

While larvae are still present in the mine or roll, particularly in the large late instars, they are hunted by birds which eat out the area of the mine or roll containing the larvae, leaving large holes and tears in the leaf.

9.v. Two Or More *G. syringella* Mines In One Leaf

The female, ready to oviposit, selects a leaf large enough for the complete development of an egg mass. Usually she does not deposit a second egg mass on a leaf that already has an egg mass on it. Two mines were found to occur on 13.31% of the examined mined leaves, three or more were present on 2.92% of the mined leaves (Fig. 27). In the ovaries of field caught females there were 10-20 mature eggs present at one time, enough for two egg masses but egg masses found on the same leaf were usually of distinctly different ages; they were probably not laid by the same female. Different females may each successfully lay one egg mass on a single leaf. In the laboratory, tests were tried in which females were given a choice of a clean leaf and a leaf with one egg mass already on it. These tests were inconclusive because egg masses, in addition to being deposited on the glass sides of the cages, were deposited on both the upper and

lower leaf surfaces, which very rarely (Section 5. B. v.) happened in the field.

10. POPULATION ESTIMATION

10.i. Percentage Of Infested Leaves

The percentages of lilac leaves infested by Gracillaria syringella in the study area in Calgary during the spring generation of 1964 were calculated and are shown on Fig. 28. The percent infestations from June 3 to June 30 were calculated from direct counts of leaves on bushes while those from June 30 to Oct. 11 were from the collections of leaves taken for larval population samples. There was a gradual increase during the first generation as the leaves were mined and then rolled (Fig. 29); some of the larvae moved on to uninfested leaves after leaving the mines. The peak infestation was on July 16 after which there was a decrease as pupation began and new leaves were produced by the lilac bushes. The most extensively damaged of the leaves were shed (Fig. 30), contributing to the decrease. The moths from the spring generation began to emerge and lay eggs on July 27 and the infestation from this second (autumn) generation was not noticeable until the eggs hatched and mining began. There was no noticeable increase in the percentage of infested leaves until the leaf rolling stage was reached. During the mining stage the bushes were able to produce new leaves faster than mines were formed. The plant's growth slowed down in Sept. and the bushes shed their leaves in mid-October; all the leaves were lost by Oct. 23.

10.ii. Larval Populations

During the summer of 1964, 100 lilac leaves were picked every

three days during the second generation as described in Section 4. The collections began on June 30, after development was advanced and ended on Oct. 1. The average numbers of live and dead larvae per mine are shown in Fig. 31. The mean number of eggs per mass was 7 and 84% of these hatched, that is, an average of 5.9 eggs per mass developed into larvae in the first generation. 138 eggs were observed during the first generation; 9.5% died after hatching because they came out onto the surface of a leaf. After this no other mortality factors were found and by July 4 there were still 5 live larvae per mine present. When pupation began there were 4.2 live larvae per mine, indicating a total larval mortality of 1.7 larvae per mine at 28.8%. There was a loss in numbers of live larvae in the mines from July 7 (the beginning of pupation) to Aug. 6 because of mortality and pupation. It is difficult to separate loss by mortality from loss by pupation as the larvae drop to the ground to pupate. There was a great increase in numbers after Aug. 6 as the eggs laid by the first generation moths hatched. The greatest average number of live larvae per mine was 6, present on Aug. 26. The summer generation of adults was spread out from July 7 to Sept. 15. The eggs took an average of 7 1/2 days to hatch in the field. The peak in larval numbers appears to suggest that the main batch of eggs was laid about Aug. 19. The loss in numbers during the following days was due to mortality. The larvae which did not succeed in entering the leaf were found near the egg masses and accounted for 7.5% of the total number of larvae. Other mortality factors are discussed in Section 11. When pupation began

in the second generation there were 4 live larvae per mine present, indicating a larger total larval mortality than in the spring. There was a 33% decrease from the peak number to the onset of pupation.

The numbers of dead larvae per mine were recorded. Molt skins, even the first instar head capsules, could be found in old, vacated mines. The body contents of dead larvae decayed and the remains could not be recognized more than two weeks after death, therefore, the curve is not cumulative. There are no distinct peaks in the curve showing numbers of dead larvae; at no time was there a large mortality. The slight increase in numbers of dead larvae during the last two weeks in Sept. was due to frost kill. It is probable that frost kill was more severe than is indicated by these data because low temperatures slowed the decay and after preservation in alcohol, recently dead larvae were difficult to distinguish from those which had been living. In the field, larvae killed by frost, before decay, appeared similar to live larvae except that they were very soft. In alcohol, the softness of these larvae could not be detected.

10.iii. Pupal Populations

When the first generation larvae began to pupate, 45 aluminum pie pans filled with soil were placed under the three bushes of group A, as described in Section 4. After the larvae had ceased dropping, the pans were individually placed into muslin bags and left under the bushes. The 309 moths that emerged from thepans were collected; none were from the 11 pans under the outer edges of the bushes. When emergence

was over, all of the 45 pans of soil were sifted for larvae and pupae but none were found in the outer 11 pans. The other 34 pans contained 94 dead pupae; 74 bare and 20 in cocoons. No parasites were found in them. Dead larvae were not found in the soil, probably due to decay. Moths emerged from 76.7% of the pupae. The area of the soil in the 34 pans was 11.6 sq. ft. The area of ground covered by the bushes was 75.6 sq. ft. If the sample in the pans was representative, then only 1966 moths would have emerged from the total area under the 3 bushes. The sample may not have been representative because soil-covered cocoons are almost impossible to distinguish from lumps of soil. Though the lumps in the pans were broken up, a few of the cocoons could have been missed. It was observed that some larvae wandered before burrowing into the soil. It is more likely that larvae landing in the pans would wander out, than that larvae landing on the soil surface would climb into thepans. Thus, it is probable that the pupal population estimate is low. Digging in the ground under the bushes for pupae was attempted but their size and soil cover, plus the presence of many grass roots made it almost impossible to find them.

The pans were also placed under these bushes when the autumn generation began to pupate. The period between Sept. 14, when pupation began and Oct. 23, when all the leaves were gone off the lilac bushes, was dull, windy and wet. There were freezing temperatures on 9 days and the wind speeds were above 25 mph on 10 days. There were 1.98 inches of precipitation, including some snow.

On several occasions the pans filled with water before they could be covered. The winds dried up the soil in the pans forming a hard crust that descending larvae could not penetrate. These larvae crawled over the edges of the pans and fell to the ground. During the winter the soil in these pans was sifted but little was found. Larval remains were not seen due to decay. 25 of the pans had nothing in them and the other 20 had only about three pupae in each of them, none appeared to be alive. No worthwhile estimate of pupal population could be calculated for this generation.

10.iv. Moth Populations

The adult populations were sampled at various times during 1964 from group A bushes. An estimate of the population was made using the formula $P = N \times M/R$ where, from the area selected, M is the number of moths captured, marked, and released and N is the number of moths captured on a second occasion, including R marked ones. This equation (from Andrewartha, 1961) implies that the marked moths, after release, distributed themselves homogeneously with respect to the unmarked ones which were not caught and that the recapturing was done immediately after the releasing, or at least before there was time for any marked ones to die or leave the area, or for any immigrants to enter the area. In the spring moths were marked as described in Section 4, released in the morning and recaptured the same day. Fine days were chosen when the moths were active and the marked ones mixed in with the population quickly. The recapturing was done

over the whole area of the three bushes. The adults that emerged in the spring of 1964 from overwintered pupae were sampled on June 3, 1964. The population clearly increased following this date and was re estimated on June 10. An estimate taken on Aug. 5 seemed to be at the peak of the August (summer) generation of moths (Table 5). The population was obviously larger than that in the spring and a larger number of moths was marked and released.

TABLE 5

Moth Populations

	Spring Emerged Moths		Summer Emerged Moths
	June 3, 1964	June 10, 1964	Aug. 5, 1964
Initially Captured and Marked	42	70	217
Second Capture	39	54	195
Number of Marked Recaptured	4	5	12
Time Interval Between Initial Capture and Second Capture	6 hr.	8 hr.	24 hr.
Estimated Population	410	756	3526

On calm, warm days, both in bright sunshine and in the evenings the moths were easy to observe. Daily observations indicated that their numbers built up quickly and decreased gradually. A good estimate of moth longevity could not be obtained. In the field caged moths died in two days as mentioned in Section 5. B., but conditions here were very

different from those in the field. Without accurate data on longevity the total number of moths emergining in the summer of 1964 could not be calculated, but it must have been greater than the estimated peak number of 3526.

The total size of the 1964 autumn larval population was estimated. On Aug. 26, 67% of the lilac leaves in the study yard were mined and there was an average of six larvae per mine present (Fig. 31). At the end of Aug. the number of leaves per bush in group A was estimated by counting leaves on branches of various sizes, multiplying each result by the number of branches of that size on the bushes and summing them. A total of 5870 leaves was estimated to be on the three bushes; 3933 of these were mined. From Section 9.v., 16.23% of the mined leaves examined had two or more mines in them, so the estimated total number of mines was 4571 and the estimated total larval population six times this, 27,426. From Section 5.B.iii, the mean number of egg masses per female was 111/7 or 15. One egg mass produces one mine, so 4571 mines indicate 4571 egg masses, which could have been laid by 305 females. Thus, the total population of first generation adults necessary to produce this infestation, since the sex ratio is 1 : 1, would have been 610 moths. A very quick, superficial count of the moths in the area of these bushes clearly indicated a population greater than this. Large numbers of moths were very quickly counted. Neglecting the fact that some of the leaves, those shorter than 35 mm, were too small to support an egg mass, if all the leaves were mined and if every female laid 15 egg masses, a

100% infestation could be produced by only 391 females, indicating a total population of 782 moths. The eggs producing this autumn generation of larvae were laid by the 1763 females of the 1964 summer generation of 3526 moths. If the 3526 moths were the total population, and it is probably a low estimate, as explained above, then the average number of egg masses laid per female would only have been 2.59. This is much less than the 15 egg masses they are capable of producing, therefore, the full reproductuve capacity was not reached in the field.

The total larval population, as calculated above, would have been 27,426 on Aug. 26, 1964. At the onset of pupation, on Sept. 14, the population had dropped to 3.98 larvae per mine, or a total population of 18,192. If all the larvae pupated successfully and survived the winter, 18,192 adults could have emerged in the spring of 1965; this is a much greater population than the 3,526 of the previous (1964) summer generation. In fact, during each of the three years of this study, the number of moths emerging in the spring was considerably smaller than the number of summer generation moths. The adult population estimate taken on June 11, 1965 at what appeared to be the peak, indicated only 210 moths. The number of moths marked and released on June 11 was small because of the low population, therefore, the population estimate may have been inaccurate. In the spring, emergence from the overwintered pupae is more synchronous than the summer emergence; the peak estimate would include nearly the whole population. Assuming the population was 210, the overwintering mortality would have been 98.8%. This contrasts with the mortality

during the pupal stage of the spring generation of 1964 which was 23.3%. As reported in Section 10.iii., the conditions at the time of pupation in the autumn of 1964 were very unfavorable, the soil surface being alternately deluged and dried to a crust. It is likely that few of the larvae managed to dig into the soil to pupate.

11. MORTALITY FACTORS

11.i. Parasites

Gracillaria syringella eggs did not appear to be parasitized at any time.

The rate of parasitism in G. syringella larvae was low. During the spring generation of 1963, 0.9% of the larvae found were parasitized, 9 parasite eggs and 9 parasite larvae were found. Larvae from the autumn generation of 1963 were not examined for parasites. During the spring generation of 1964, 0.19% of the G. syringella larvae examined were parasitized and during the autumn generation, of the 4,400 larvae examined, 0.15% were parasitized.

The parasite eggs included at least 5 different types, 1 internal and 4 external, which were distinguished by size, shape and chorion pattern. Three of the 4 external parasite egg types were present only in very small numbers; 1, 2 and 4 specimens of the 3 rarer types and 42 eggs of the most common type were found. There were only 2 different types of external larvae distinguishable. One of the external larvae could be associated with its egg because 1 partly hatched larva was found and 4 mature larvae inside the chorion. The associated egg type was the one that was most numerous. An internal larva was found only in a G. syringella pupa.

Late in the autumn generation of 1964, on Oct. 11, ichneumonids were observed to fly around the lilac bushes. Females flew to rolled leaves and moved their antennae quickly over the surface of the roll.

Then they would either oviposit into the roll, through the leaf, or move onto a new roll. Some of these rolls were examined; those they oviposited in had G. syringella larvae in them; those left had no larvae in them. Several of the leaves that the ichneumonids had oviposited in were collected and kept in petri dishes in the laboratory. By Nov. 25, adults had emerged from these; they were identified by G.S. Walley as Scambus hispae (Harris). When the rolled leaves were opened, remains of a parasitized G. syringella larva and parasite pupal skins were found. The associated egg and larva mentioned above may be S. hispae or a close relative as the egg is similar to the description of S. hispae eggs given by Arthur (1963). The larvae appear similar but since they are only early instars and there has not been sufficient work done on the earlier stages of hymenopterous larvae, they could not be identified positively. No parasite pupae were found. S. hispae is a common external larval parasite of Lepidoptera. One S. hispae type larva was found in the spring generation and 16 in the autumn generation. S. hispae has 2 generations per year as does G. syringella. It is distributed from the Atlantic to the Pacific in the Canadian Transition Zone. It has never been reported on G. syringella before, though it has been found on other hosts in Alberta and could have moved onto the leaf miner from these. This seems to be indicated as the adult parasites were numerous yet the larval parasitism was low.

When autumn generation pupae were in the soil, on Oct. 11, ichneumonids were noted to be flying close to the ground and appeared

to be ovipositing. Some of the ovipositing ichneumonids were collected and sent to G.S. Walley who identified them as Itoplectis quadricingulata (Provancher). When the areas where they landed were examined, G. syringella pupae were found. 25 of these were collected and kept in the laboratory. On Dec. 1 they were opened; all were dried up except one in which there was a parasite larva. This was mounted and found to be in the second or third instar. The head capsule and mouthparts were different from those of the S. hispae type larvae. It was possibly an I. quadricingulata larva but a last instar larva is needed for positive identification. I. quadricingulata, a common and widely distributed native species in North America, is an internal parasite of lepidopterous pupae. It has never before been reported from G. syringella though it has been found in Gracillaria sp. on Rosa in Alberta.

Parasites found in Europe on G. syringella are listed in "Parasitinsekten der Blattminierer Europas" by Fulmek (Appendix iv.).

11.ii. Predators

Ants, identified by J. Sharplin as Formica neoclara Emery were observed carrying G. syringella pupae and newly descended fifth instar larvae to their nests, at least 20 ft. away from the lilac bushes. They were also seen to climb up the trunks of the lilac bushes but were not actually seen attacking larvae in the mines.

Lacewing (Chrysopa sp.) eggs (4) were seen on branches of

lilac. They were collected and kept in a petri dish with a mined lilac leaf containing larvae. The first Chrysopa hatched, devoured the other eggs but did not touch the G. syringella larvae.

A yellow warbler (Dendroica petechia) was seen by G. Evans to attack mined and rolled leaves, presumably to get the G. syringella larvae out of them. I never observed any birds attacking the lilacs but did see some marks on lilac leaves shaped like beak marks. In Europe, sparrows (Ploceidae) were reported by Pussard (1928) to be predators.

Spiders were the most numerous of the predators to be observed. From the leaf collections preserved in alcohol of the 1963 spring generation there were indications that two species of spiders were present, identified as belonging to the Salticidae and Dictynidae. Two spider webs contained the remains of one G. syringella moth, one immature thrips, two Acalypterate Diptera, one Phoridae (Diptera), one Nematocerate Diptera and one Hymenoptera. During the summer of 1964, preserved leaf collections contained 16 specimens of seven families of spiders:-

Dictynidae - Dictyna sp.
Dictyna annulipes Blackwall

Theridiidae -

Salticidae - Thiodina sp.

Clubionidae - Clubiona sp.

Thomisidae - Philodromus aureolus (Oliver) 1789
Philodromus sp.

Tetragnathidae - Tetragnatha sp.

Araneidae - Acacesia sp.

The specimen of P. aureolus, a male, was kept in a petri dish in the laboratory from July 7, 1964 until death on Aug. 10, 1964. During this period the spider consumed 2 1/2 late instar G. syringella larvae.

11.iii. Fungus

Spores and mycelia from fungi found on dead larvae and pupae were mounted in balsam; they could not be identified. From all appearances the fungi did not cause the death of the larvae but developed on them later.

11.iv. Weather

Late spring frost may cause localized injury to young lilac leaves by killing or splitting the tissue in the intervein areas; later the leaves appear as if torn (Herald, 1943).

TABLE 6

Year	Emergence of First (Spring) Generation	Last Day of Frost in Spring	First Day of Frost in Autumn	Beginning of Pupation, Second Autumn Generation
1963	May 19	May 19	Oct. 19	Sept. 1
1964	May 26	May 26	Sept. 6	Sept. 14
1965	May 27	May 21	Sept. 5	Sept. 5

Temperatures in the late autumn fluctuated very much; frosts

occurred on widely scattered nights before the freezing temperatures were continuous. The first frost (Table 6) did not seem to injure the G. syringella larvae, though the lower temperatures slowed down their development. Continuing freezing temperatures killed larvae in the mined leaves. Newly dead larvae were found after each night of freezing temperature. Some larvae that survived the frost were still in the mined leaves when they were shed by the bushes on Oct. 23; these larvae were not far enough developed to pupate and presumably all died.

12. DISPERSAL

The moths marked for population studies were also used to give some estimate of dispersal. Marked moths kept in the laboratory lived as long as unmarked moths under the same conditions; an average of six days. Moths in the field were assumed to have lived at least this long or longer. The marking consisted of dye powder dusted among the scales on the moth's body (Section 4) and the marked ones could apparently fly as well as the unmarked ones. On Aug. 5, 1964, 16 of a sample of 195 moths taken from the bushes of A group were marked. On Aug. 6, 2 out of 65 moths in the same area were found to be marked. On Aug. 8, three days after the initial release, one marked moth was found among 98 captures. Assuming that the marked moths were all still alive after three days and that the population remained stable with no great increases, it appears that about 90% changed bushes in the three days. Several days after all three marking experiments (Section 10.iv.) the surrounding bushes in the study yard, in the front yard and in the neighboring yard, were searched for marked moths. One marked moth was captured 16 ft. away from the point of release and one was caught 30 ft. away. Marked moths escaping into the surrounding bushes were so diluted in numbers that the chances of finding one were small. In addition to the marking experiments, observations of the flight habits of the moths were made. Groups of between 3 and 10 moths flying around one another were often observed during the daytime to move out 6 ft. or more from the bushes

and return. Individual moths were seen to fly up to 50 ft. away from the bushes on calm days. At the time moths were seen to fly around the bushes in great numbers; winds varied up to 15 miles per hour. The moths stayed in the shelter of the bushes when the winds were over 20 miles per hour. A moth outside the perimeter of a bush was quickly blown down wind out of sight.

As reported in Section 3.iii., the lilac leaf miner spread across most of the northern United States and southern Canada in recent years. This spread could have been accomplished by the moths flying, aided by wind, or some life stage being transported in lilac. Nursery stock arriving from Europe enters the country at Vancouver, Montreal and Halifax and is shipped to various points in Canada. Until recently (Section 3.iii.) lilacs, particularly the French hybrids were often shipped in soil balls; pupae may have been in the soil around the roots. After May, 1965, importing lilac with soil-covered roots was prohibited. They are shipped bare-rooted or in peat moss; it is unlikely that pupae are now transported in this manner. In local situations, people, when giving lilac bushes to their friends, do not usually remove the soil from the roots; it is possible the pupae could be carried several hundred miles or more in this way. Gracillaria syringella, in the leaves of bouquets of lilacs would be present in the egg and larval stages. When the flowers faded they would not be ready for pupation, therefore, the chance of spreading infestation with bouquets is small.

The moths can move a reasonably long distance without having

to be transported in lilac. Along the 190 mile stretch of the #2 Highway between Calgary and Edmonton, farm yards containing lilac bushes were found to be an average of 2.5 miles apart, the greatest distance between lilac bushes was 10 miles. The moths were first recorded from Calgary in 1960; they were established by 1961 and arrived in Edmonton in 1964. The 190 miles was covered by the moths in four years, a rate of 47.5 miles per year. Meteorological data from 1964 indicated that there were only eight days a year during the moth stage on which there were south winds blowing. The average windspeed for this period was 10.4 miles per hour; the greatest windspeed was 23 miles per hour, the winds reached 15 miles per hour or over on six of these days. As indicated, the moths are able to fly in winds up to 15 miles per hour but some would also fly with the wind and be aided by it. Daytime activity of the moths around the bushes is described above. At dusk they were more venturesome and flew right away from the bushes. This type of activity lasted about two hours per evening. Individuals, as mentioned previously, were able to fly at least 50 ft. in one flight, without the aid of wind. A group of randomly flying moths situated near the northern edge of Calgary were observed; at least some were flying down-wind, aided by the wind. Under ideal conditions, if they were carried entirely by the wind, *G. syringella* moths could move, or be moved 20.8 miles, or four farms away, in one evening of flight. To move 47.5 miles would require only three evenings of wind-aided flight. Thus, the spread from Calgary to Edmonton over a four year period

could be accounted for by wind-aided flight.

Gracillaria syringella was in Vancouver by 1928, in Penticton by 1941 and had reached Calgary by 1960, a period of 32 years and a distance of about 850 miles. The rate of movement was 27 miles per year. The lilac leaf miner was established in the St. Lawrence area by 1923 and had reached the coast of Maine by 1932, a distance of 320 miles moved in nine years; a rate of 35 miles per year. There were no distances across the continent covered more quickly than this, thus, it is possible that *G. syringella* could have spread across the country by only wind-borne flight. Whereas the lilac leaf miner was almost certainly introduced to North America in the pupal stage in soil, its rate of spread is no faster than could be accounted for by wind-aided flight.

13. CONTROL

The picking of the mined leaves early in the season and burning these may hold the pest in check to some extent; while this plan lends itself more conveniently to treatment of small bushes, it is obviously too tedious and impractical for the larger bushes. It took a total of 32 minutes picking time to keep a small lilac bush, 3 1/2 ft. high free from mines during the first generation of 1964. After a total picking time of over 40 minutes during the autumn generation it became obvious that too many leaves were mined on this bush to make direct control practicable.

During the winter exposing the pupae by breaking up the soil surface may also help keep the insect in check.

During 1964, the Canada Department of Forestry recommended a systemic insecticide, Dimethoate for control of the lilac leaf miner. It was available to the home gardener under the trade names Cygon and Rogor. The rate of application recommended was Cygon 2E, at one teaspoonful of the emulsifiable concentrate in 1 gallon of water or Rogor 40 at 1/2 teaspoonful in 1 gallon of water. A neighbor agreed to use Cygon on his lilacs at the recommended application and dosed the lilacs with Cygon around the roots 5 times during the summer. His lilacs remained free of the leaf miner but the test was invalidated as he also sprayed with a mulit-purpose spray twice. Another insecticide, Diazinon, was recommended at the rate of 2 pints in 100 gallons of water when the larvae were first noticed.

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15. APPENDICES

i. Distribution of Lilac leaf miner, Gracillaria syringella (F.) in Canada.

This list includes all records for: The Canadian Insect Pest Review, The Canadian Insect Pest Record, the Canadian National Collection of Insects and my own collections.

British Columbia

Agassiz

Chilliwack

Huntingdon

Kamloops

Kelowna

Nelson

New Westminister

Penticton

Salmon Arm

Sidney

Summerland

Trail

Vancouver

Vernon

Victoria

Alberta

Calgary

Alberta (cont.)

Drumheller

Edmonton

Fort McLeod

Innisfail

Lethbridge

Pincher Creek

Red Deer

Manitoba

Winnipeg (1965)

Ontario

Acton

Ailsa Craig

Apple Hill

Avonmore

Belleville

Bethany

Ontario (cont.)

Bobcageon

Bonarlaw

Brantford

Brockville

Brooklyn

Canan

Cobourg

Cordova

Cornwall

Dixie

Durham

Fort Erie

Fort William

Glen Gordon

Guelph

Hamilton

Harold

Ontario (cont.)

Hastings County

Havelock

Kitchener

Lancaster (Glengarry)

London

Madoc

Manchester

Manitoulin Is.

Manotick

Marmora

Martintown

Meadowvale

Monkland

Mono Road

Myrtle

Nestleton

Newcastle

Ontario (cont.)

Newmarket

Niagara Falls

North Bay

Norwood

Orillia

Oshawa

Ottawa

Perth

Peterboro

Pickering

Port Perry

Prescott

Preston

Richmond Hill

St. Catharines

St. Marys

Sarnia

Shanby

Sharon

Simcoe

Smith Falls

Spencerville

Stirling

Stouffville

Ontario (cont.)

Strathroy

Sudbury

Toronto

Uxbridge

Whitby

Willowdale

Wingham

Quebec

Aylmer

Clarenceville

Forster

Grand Mere

Hemmingford

Henrysburg

Iberville

Lacolle

Lac St. Jean

Matapedia

Montreal

Mount Laurier

Normandin

Oka

Point au Pic

Quebec (cont.)

Quebec

Rimouski

Roberval

St. Alexandre

St. Jean

Waterloo

New Brunswick

Blackville

Boiestown

Campbellton

Caraquet

Dalhousie

Doaktown

Fredericton

Leidlow

Loggieville

Millerton

Moncton

Newcastle

Sackville

Saint John

St. Leonard

Sussex

New Brunswick (cont.)

Tabusintac

Tracadie

Waweig

Nova Scotia

Amherst

Annapolis Royal

Baddeck

Bridgewater

Chester

Cumberland Co.

Digby

Halifax

Lourdes

Truro

Wolfville

Prince Edward Island

Alberton

Charlottetown

Kensington

Summerside

Newfoundland

Avalon Peninsula

Newfoundland (cont.)

Bonne Bay

Grand Falls

St. John's

APPENDIX ii.

Distribution of Lilac leaf miner, _Gracillaria_ _syringella_ F.

in the United States

Colorado - Statewide

Idaho - Moscow

Maine - Augusta
Dover-Foxcroft
Fort Fairfield
Howland
Mt. Desert Island
Naples
Orono
Patten
Sherman Mills
Spruce Harbor (Stonington)

Massachussetts - Statewide

Minnesota - South statewide

Montana - Statewide

New Hampshire - Colebrook
New Ipswich

New York - Philadelphia

Ohio - Wooster

Oregon - Portland

Rhode Island - Statewide

Vermont - Montpelier
Statewide

Washington - Olympia
Pullman
Puget Sound

Wisconsin - Madison
Eagle River

Wyoming - Statewide

APPENDIX iii.

DEGREE-DAYS FOR DEVELOPMENT

1963. Spring (First) Generation

Eggs And Larvae - May 19 to July 6

Threshold temperature = 40°F.

$$\begin{array}{r} 49 \\ \underline{40} \end{array}$$

9, 8, 12, 16, 21, 19, 14, 7, 14, 14, 21, 23, 12/, 16, 16, 17, 13, 13, 15, 14, 15, 13, 15, 20, 20, 22, 22, 23, 26, 27, 28, 31, 23, 12, 3, 12, 18, 18, 17, 13, 19, 14, 16/, 19, 22, 27, 28, 31.

Total Number of Degree-Days = 848

Actual Number of Days = 48

Pupae - July 6 to July 28

$$\begin{array}{r} 68 \\ \underline{40} \end{array}$$

28, 33, 27, 24, 13, 15, 21, 25, 24, 14, 19, 22, 25, 30, 28, 30, 27, 17, 20, 15, 22, 24.

Total Number of Degree-Days = 503

Actual Number of Days = 22

1963. Autumn (Second) Generation

Eggs - And Larvae - July 28 to Sept. 1.

$$\frac{\begin{matrix}56\\40\end{matrix}}{16}$$

16, 19, 19, 19/, 18, 21, 23, 27, 28, 28, 27, 24, 31, 25, 25, 26, 30, 32, 24, 19, 21, 23, 27, 20, 21, 16, 18, 14, 14, 17, 17, 20, 18, 21, 21.

Total Number of Degree-Days = 769

Actual Number of Days = 35

Pupae - Sept. 1 to May 26, 1964

$$\frac{\begin{matrix}60\\40\end{matrix}}{20}$$

20, 21, 21, 24, 25, 23, 30, 29, 29, 29, 19, 23, 21, 10, 5, 1, 6, 11, 14, 13, 20, 21, 22, 13, 25, 26, 8, 16, 25, 23/, 5, 9, 1, 8, 19, 15, 13, 15, 13, 18, 22, 20, 13, 1, 18, 23, 8, 5, 15, 9, 3, 6, 3/, 1, 2, 2/, 9, 3, 1, 1/, 6, 9/, 5, 5, 2, 3, 6,, 9/, 5, 5, 2, 3, 6, 2, 4, 8, 6, 3, 10, 13/, 11, 6, 2, 1, 5, 13, 12, 6, 16, 10, 4, 6, 16, 17, 20, 25, 23, 12, 5, 11, 8, 5.

Total Number of Degree-Days = 1170

Actual Number of Days = 267

1964. Spring Generation

Eggs And Larvae - May 26 to July 7

48
40
8, 12, 13, 16, 14, 15, 13, 18, 26, 21, 23, 16, 16, 16, 17, 16, 19, 14, 17, 17, 18, 15, 11, 11, 13, 13, 13, 16, 26, 20, 20, 19, 22, 14, 17, 18, 22, 23, 17, 22, 23.

Total Number of Degree-Days = 699

Actual Number of Days = 42

Pupae - July 7 to July 27

67
40
27, 29, 32, 26, 30, 35, 25, 30, 26, 22, 19, 25, 20, 24, 28, 21, 22, 17, 20, 19.

Total Number of Degree-Days = 497

Actual Number of Days = 20

1964. Autumn Generation

Eggs And Larvae - July 27 to Sept. 14.

61
40
21, 21, 25, 20, 18, 21, 18, 28, 23, 20, 28, 28, 23, 18, 22, 28, 21, 19, 19, 22, 28, 28, 18, 18, 25, 17, 8, 11, 18, 17, 18, 11, 11, 7, 7, 16, 4, 8, 12, 16, 6, 3, 2, 3, 7, 14, 15.

Total Number of Degree-Days = 685

Actual Number of Days = 49

Pupae - Sept. 14 - May 27, 1965

51
40
11, 14, 23, 9, 7, 9, 7, 7, 8, 8, 8, 3, 5, 1, 11, 9/, 5, 9, 1, 8, 19, 15, 13, 15, 3, 18, 22, 20, 13, 1, 18, 23, 8, 5, 15, 9, 3, 6, 3/, 11, 2/, 9, 3, 1, 1/, 6, 9, 7, 5, 1, 3, 5, 8, 5, 12, 13, 9, 9/, 1, 7, 5, 3, 3, 7, 12, 11, 11, 16, 7, 8, 10, 9, 3, 1, 6, 2, 6, 6, 3, 8, 11.

Total Number of Degree-Days = 664

Actual Number of Days = 254

1965. Spring Generation

Eggs And Larvae - May 27 to July 8

59
40
19, 19, 21, 11, 7/, 14, 20, 11, 13, 18, 11, 6, 17, 25, 27, 29, 17, 12, 13, 10, 13, 13, 19, 9, 14, 19, 19, 21, 21, 17, 12, 12, 9, 11/, 21, 25, 28, 24, 27, 27, 25.

Total Number of Degree-Days = 717

Actual Number of Days = 42

Pupae - July 8 to Aug. 3

61
40
21, 19, 17, 14, 16, 18, 25, 26, 24, 26, 21, 18, 21, 18, 17, 21, 20, 25, 28, 30, 28, 22, 24, 27, 29, 32.

Total Number of Degree-Days = 587

Actual Number of Days = 26

1965. Autumn Generation

Eggs And Larvae - Aug. 3 to Sept. 5

70
40
30, 22, 21, 21, 24, 28, 28, 28, 30, 31, 21, 18, 22, 17, 23, 26, 24, 22, 22, 25, 20, 22, 22, 17, 21, 5, 7, 10, 17, 4, 8, 12, 16.

Total Number of Degree-Days = 664

Actual Number of Days = 33

APPENDIX iv.

Parasites Reported from Europe on Gracillaria syringella F. in Parasitinsekten der Blattminierer Europas. 1962. by L. Fulmek.

Braconidae: - Apanteles ardeaepennellae Bche.

- circumscriptus Nees (bicolor Nees)
- difficilis Nees
- dilectus Hal.
- emarginatus Nees (Microgaster)
- fuliginosus Wsm. (gracilariae Wlkn.)
- glomeratus L.
- impurus Nees
  - var. -
- lateralis Hal.
- obscurus Nees
- ruficornis Nees (Microgaster)
- solitarius Rtzbg. - (Hedwig) (Grapholitha)
- viminetorum Wsm.
- xanthostigmus Hal.

Ascogaster rufidens Wsm.

Bracon sbg. Glabrobracon abscissor Nees (Hedwig)

Earinus nitidulus Nees (Fahrg.)

Chalcididae: - Atoposomoidea (Cirrospilus) pictus Westw.

- - var. coxalis F.

Dibrachys sp.

Mesidiopsis (Aphelinus) subflavescens Westw.

Necremnus sp.

Pnigalio sp.

Sympiesis dolichogaster Ashm.

Ichneumonidae: - Anilasta tricincta Hgn.

Ephialtes calobata Grv.

- (Pimpla) inquisitor Scop.

Hemiteles laevigatus Rtzbg.

Horogenes (Angitia) cerophaga Grv.

- coleophorarum Rtzbg.

Horogenes (Angitia) chrysosticta Gml.

Iseropus stercorator Fb. (Pimpla)

Phaedroctonus cremastoides Hgn. (Nemeritis moderator L.)

Phaedroctonus syringellae Hedwig

Phaedroctonus (Nemeritis) transfuga Grv.

Scambus (Epiurus, Pimpla) brevicornis Grv.

Triclistus podagricus Grv.

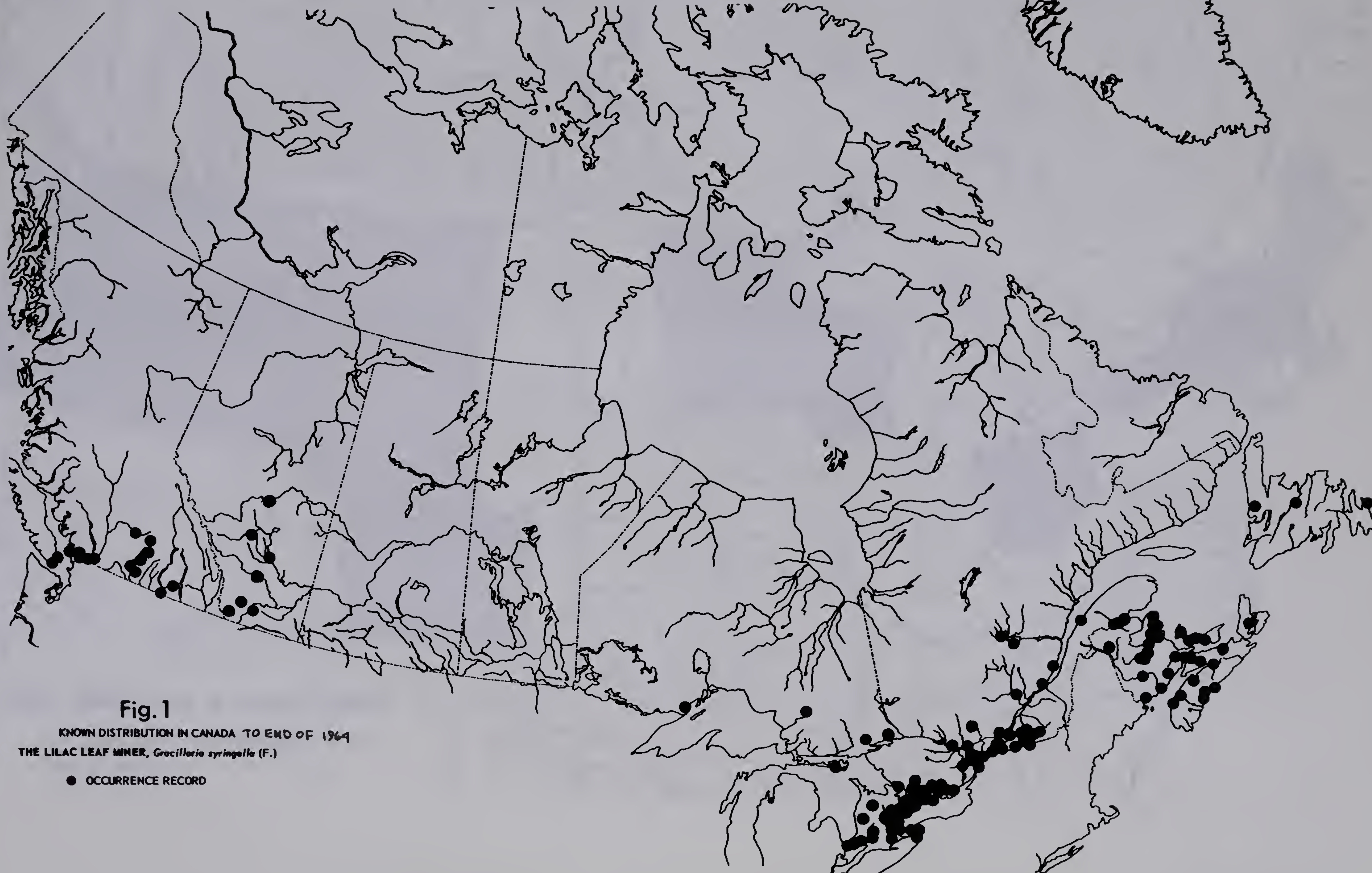

Fig. 1

KNOWN DISTRIBUTION IN CANADA TO END OF 1964

THE LILAC LEAF MINER, *Gracillaria syringella* (F.)

● OCCURRENCE RECORD

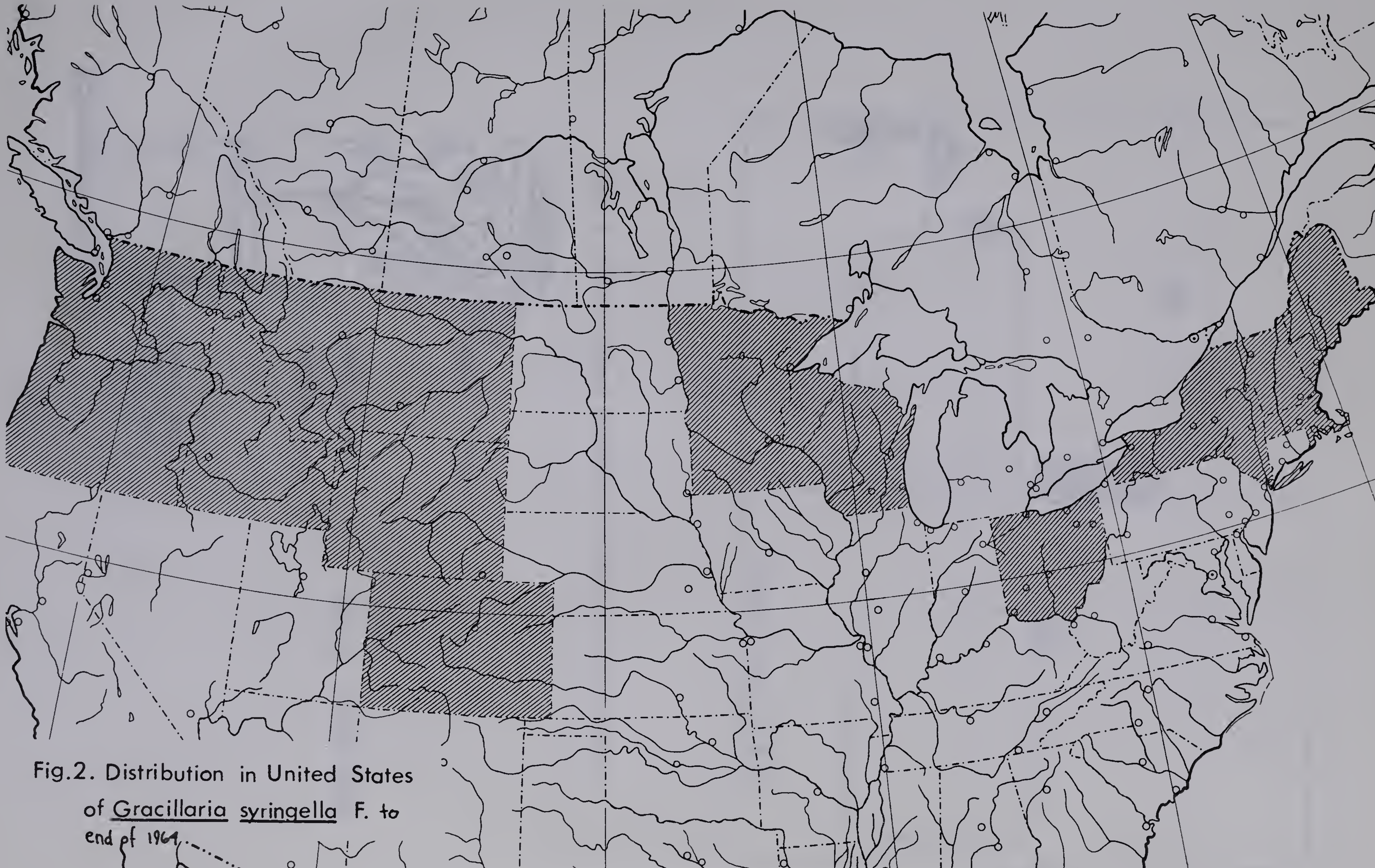

Fig.2. Distribution in United States of <u>Gracillaria</u> <u>syringella</u> F. to end of 1964.

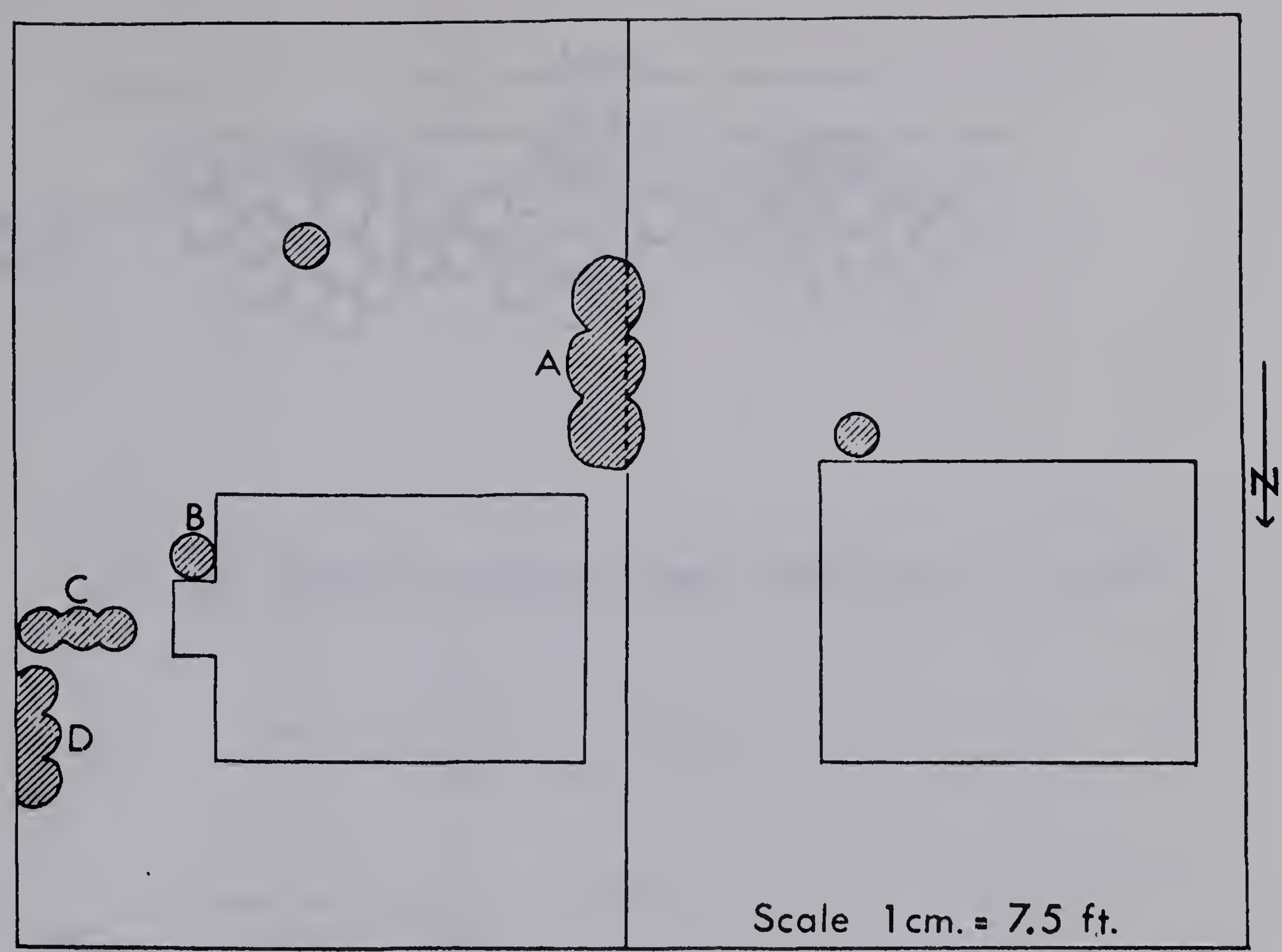

Fig. 3. Study area showing positions of lilac bushes

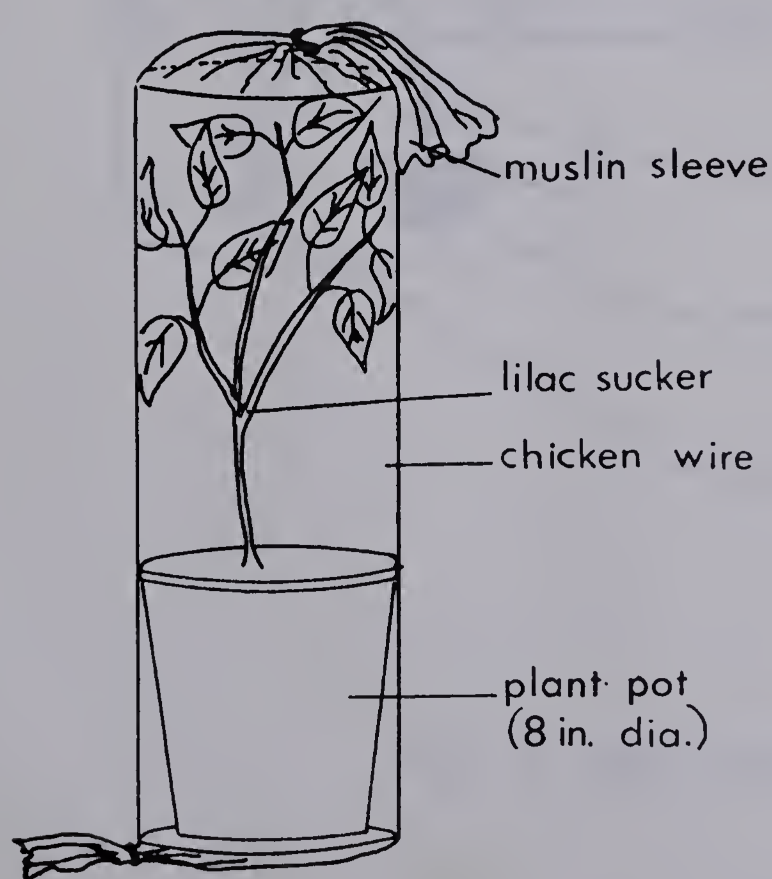

Fig. 4. Field cage

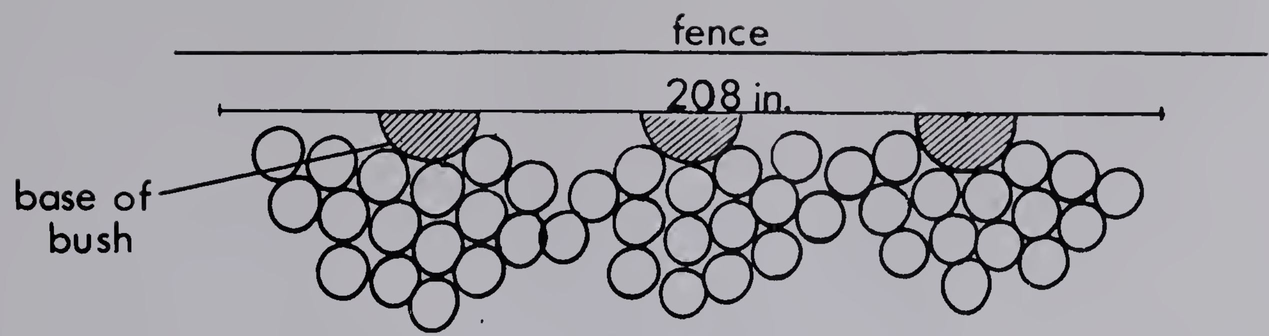

Fig. 5. Positions of aluminum pans under group A bushes

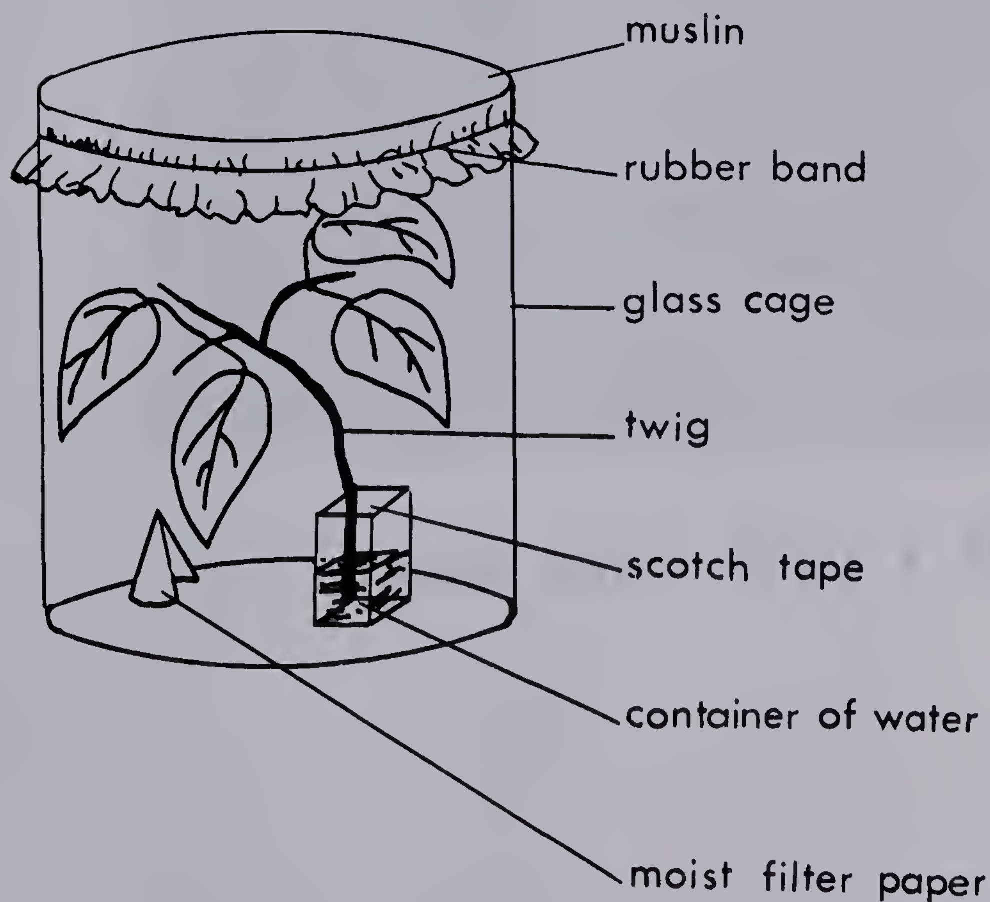

Fig 6. Glass laboratory cage

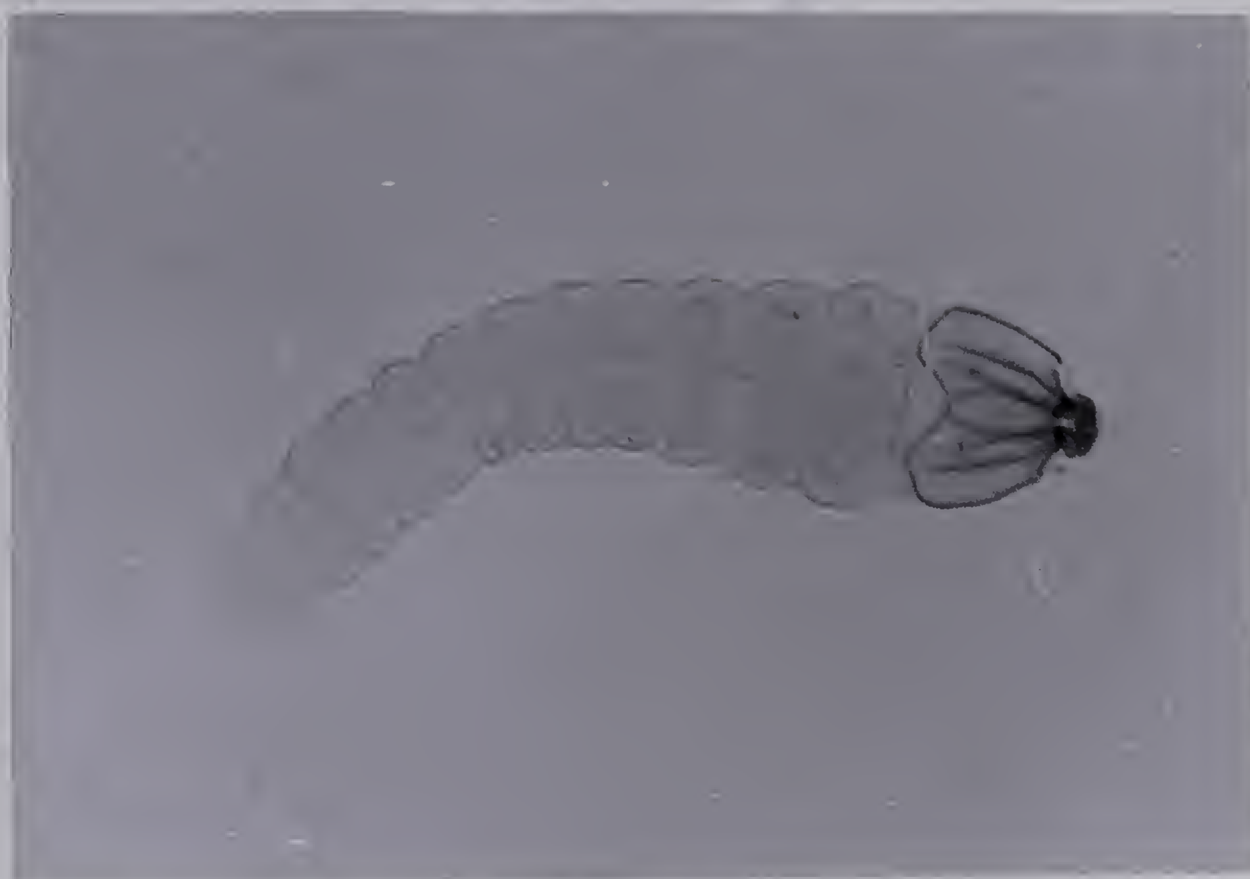

Fig.7. Second instar larva x 60

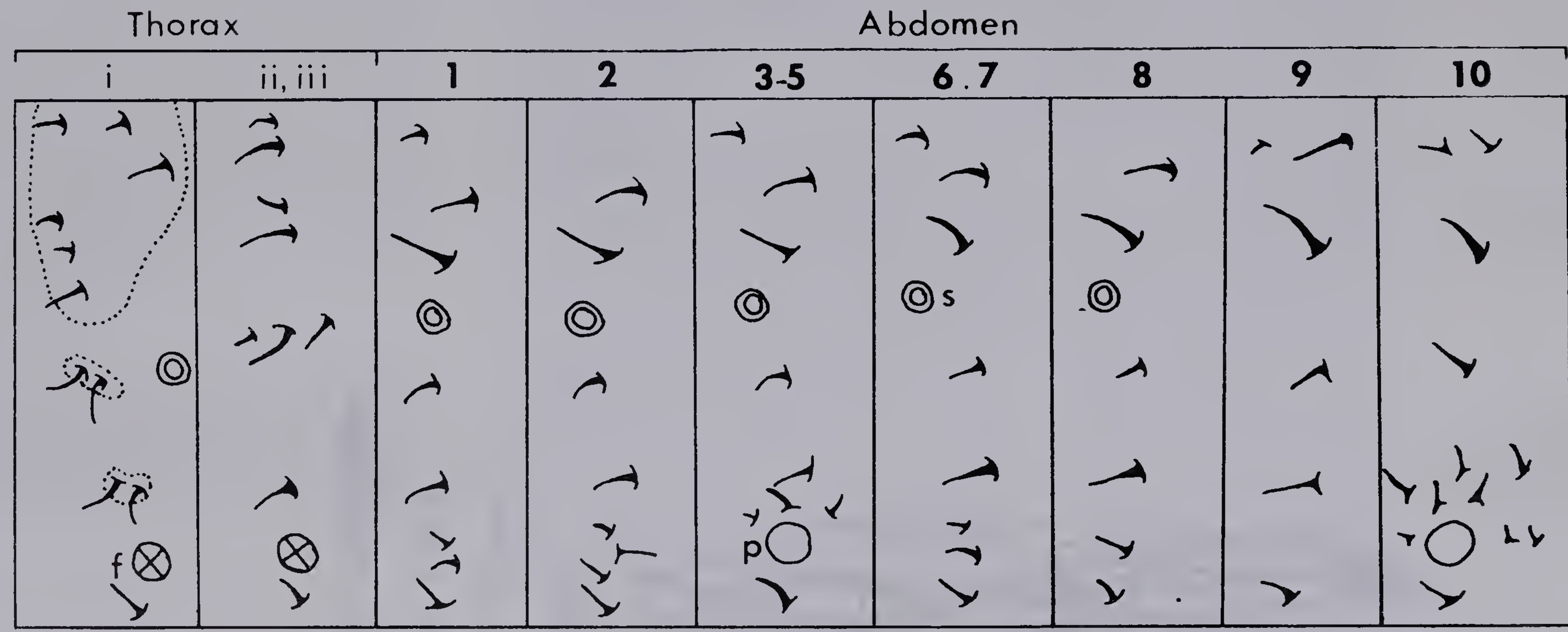

Fig. 8. Setal pattern map of fifth instar larva of <u>G. syringella</u> – lateral view x 30
f = thoracic foot, p = abdominal proleg, s = spiracle.

(after Fulmek)

ventral view

Fig. 9. Pupa

Gracillaria syringella

Fig.10. Gracillaria syringella moth x 13

Fig. 11. Lateral view of head of ♀ moth of G. syringella x 60

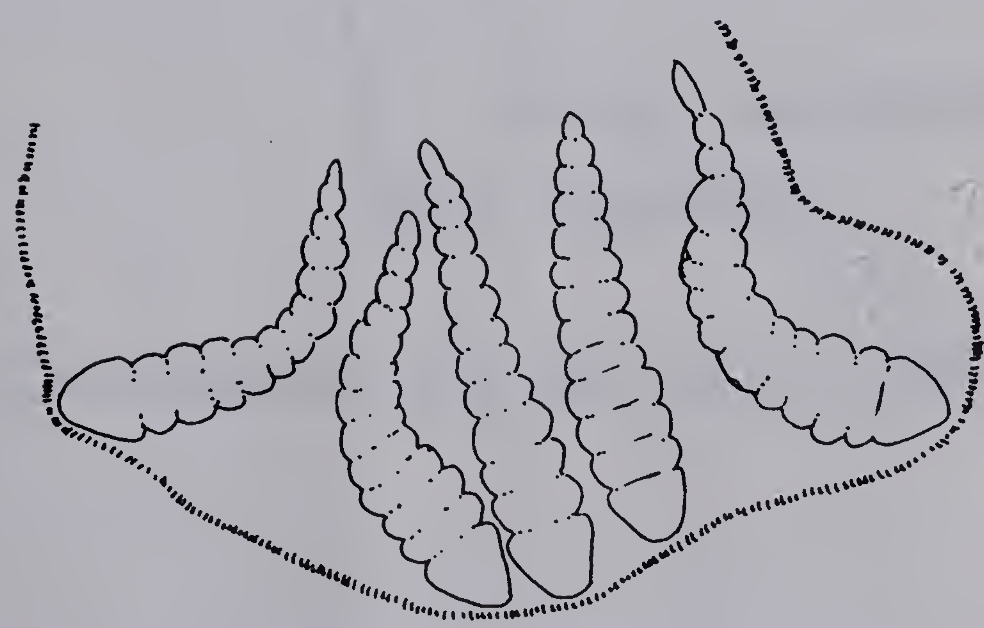

Fig.12. Gregarious first instar larvae in mine X 100

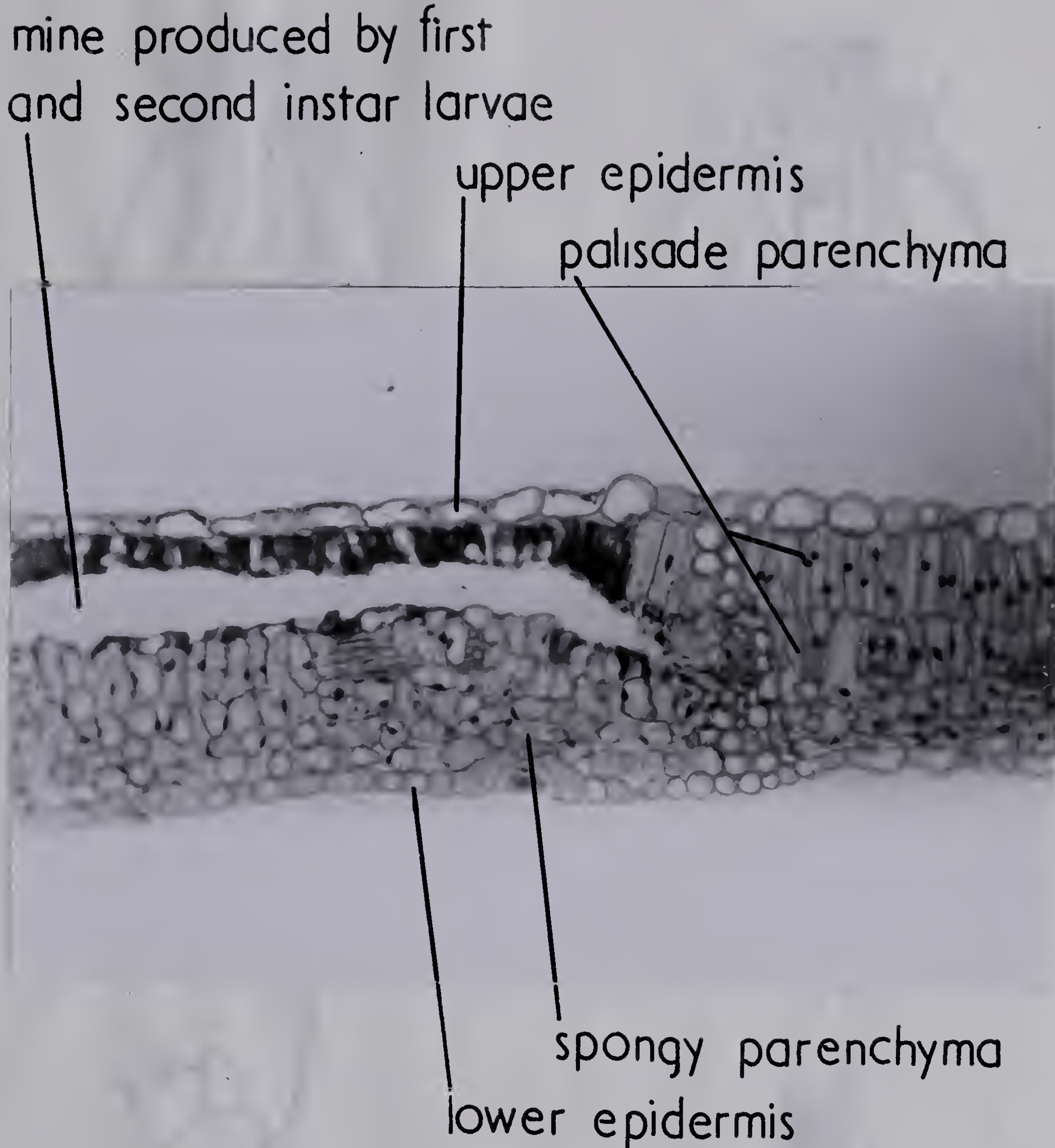

Fig.13. Cross-section of a lilac leaf. x 350

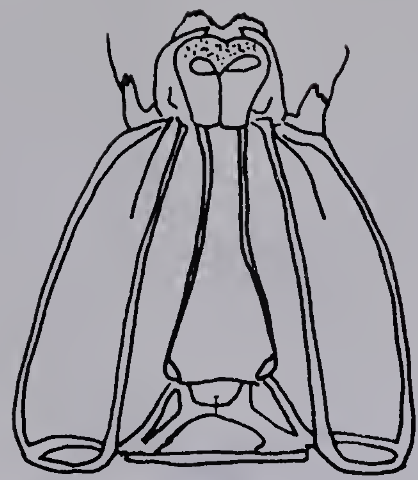

Fig.14. Ventral view, first instar head *G. syringella* x 230

Fig.16. Ventral view, fourth instar head x 80

Fig.15. Antenna of first instar larva x 1700

Fig.17. Antenna of fifth instar larva x 420

G. syringella

Fig.18. Dorsal view, labrum, first instar X 700

Fig.20. Ventral view, mandible, fifth instar X 200

Fig.19. Dorsal view, labium, first instar X 1000

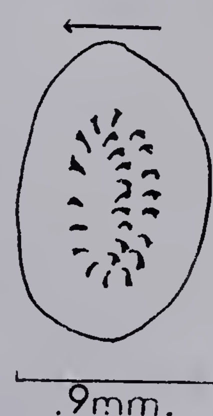

Fig.21. Crochet arrangement on proleg

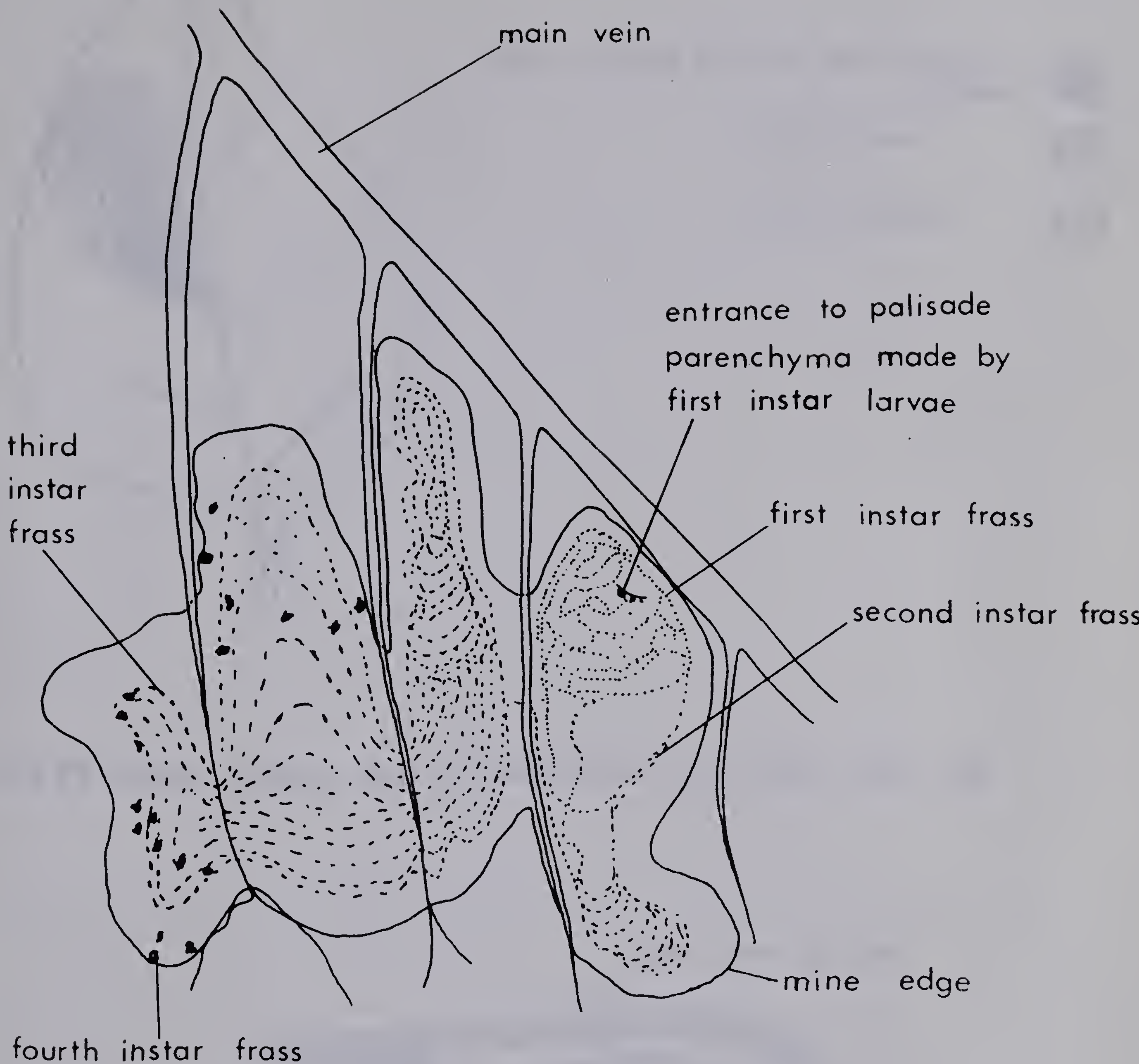

Fig.22. Upper surface view of opened mine showing larval frass patterns X 10

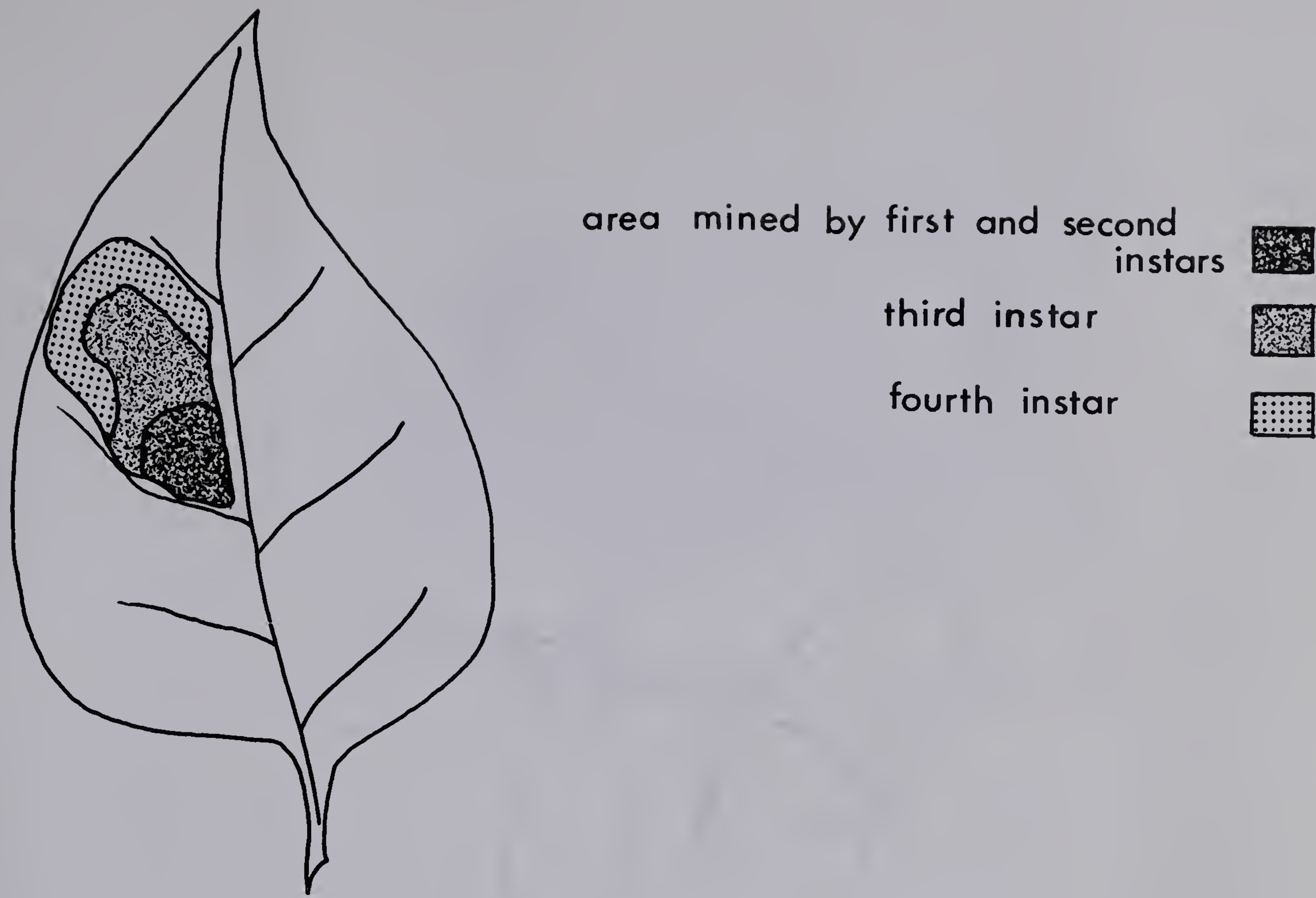

Fig. 23. Upper surface view of small mine on a lilac leaf x 1.5

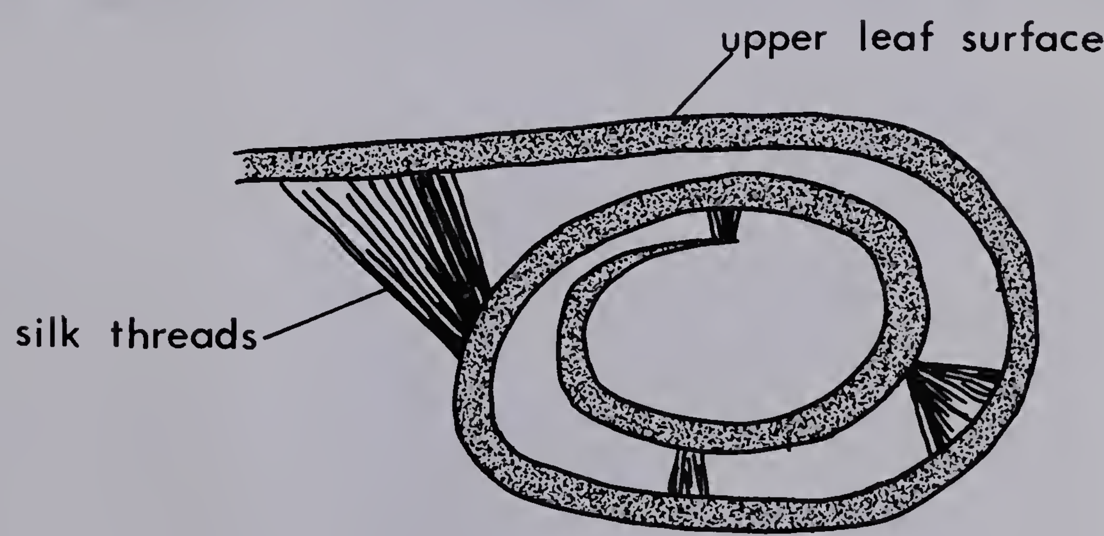

Fig. 24. Cross-section of rolled portion of a lilac leaf x 15

Fig.25. Contracted silk threads closing ends of a rolled leaf.
X 2

Fig.26. Mined and rolled leaf. x 1.5

Fig.27. Lilac leaf with several mines.
x 1.5

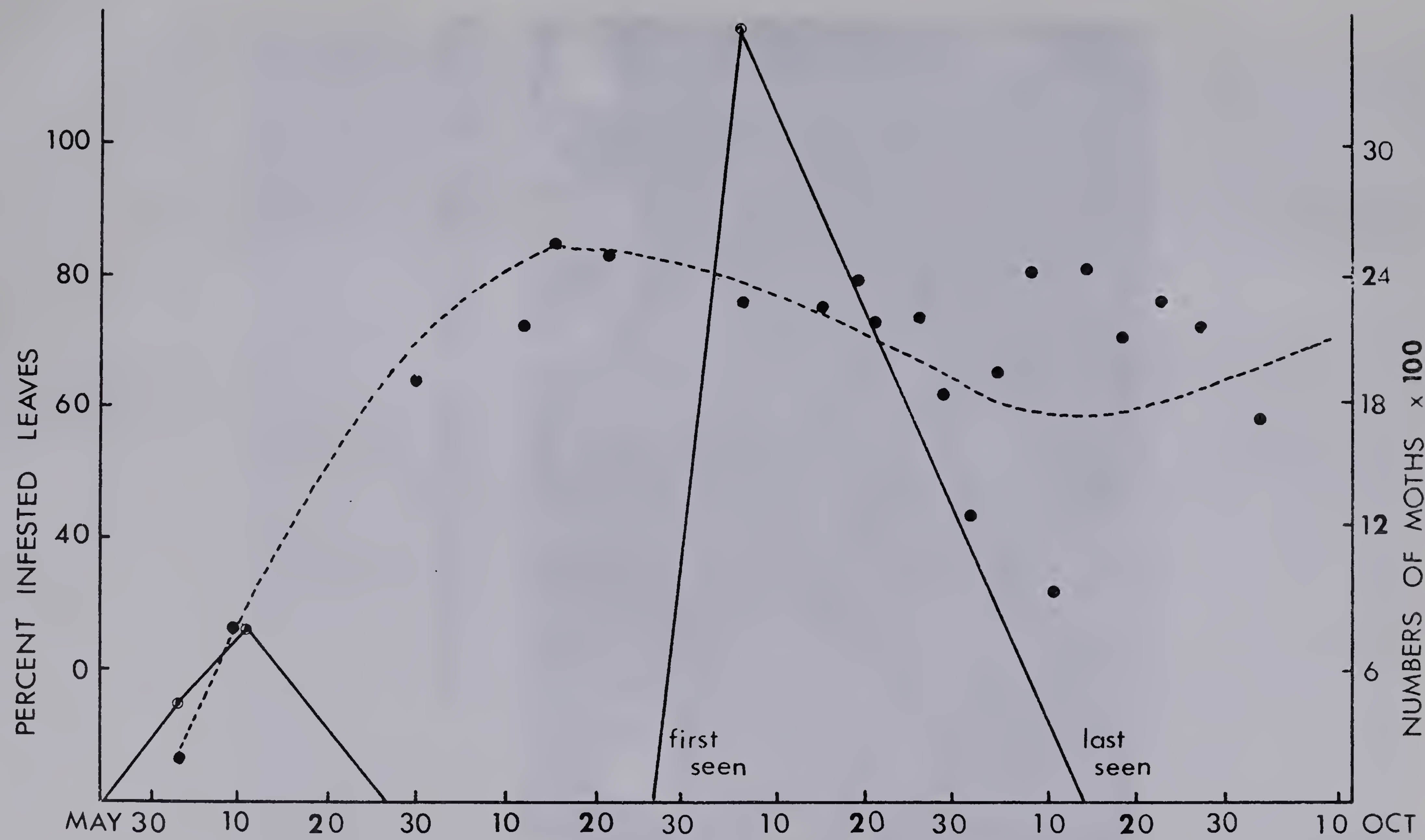

Fig. **28**. Percentage of lilac leaves infested by <u>G. syringella</u> in Calgary in **1964** ------
Populations of moths on group A lilac bushes in Calgary in **1964** ———

Fig. 29. Lilac after rolling commences.

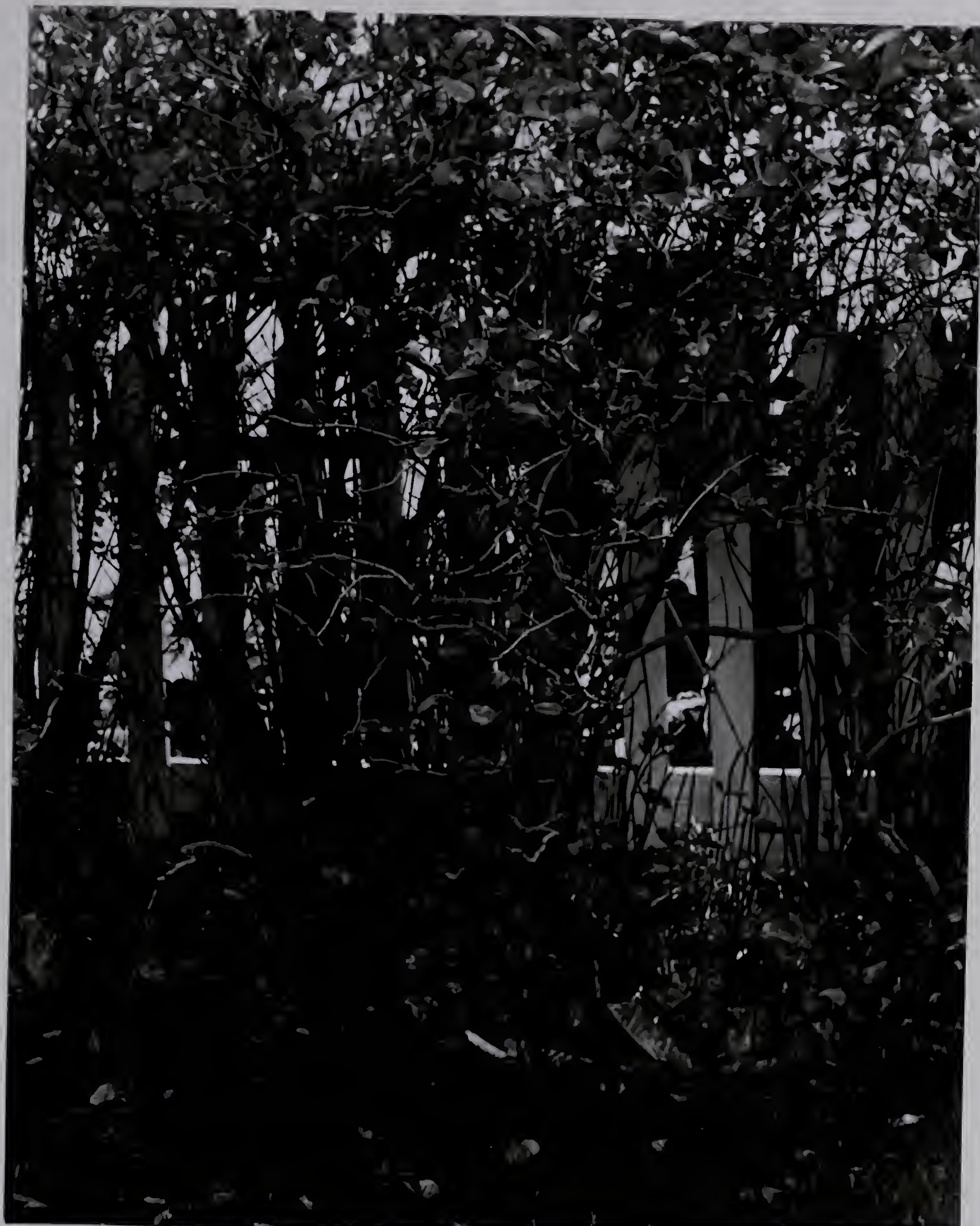

Fig.30. View of damaged leaves shed by an infested lilac bush.

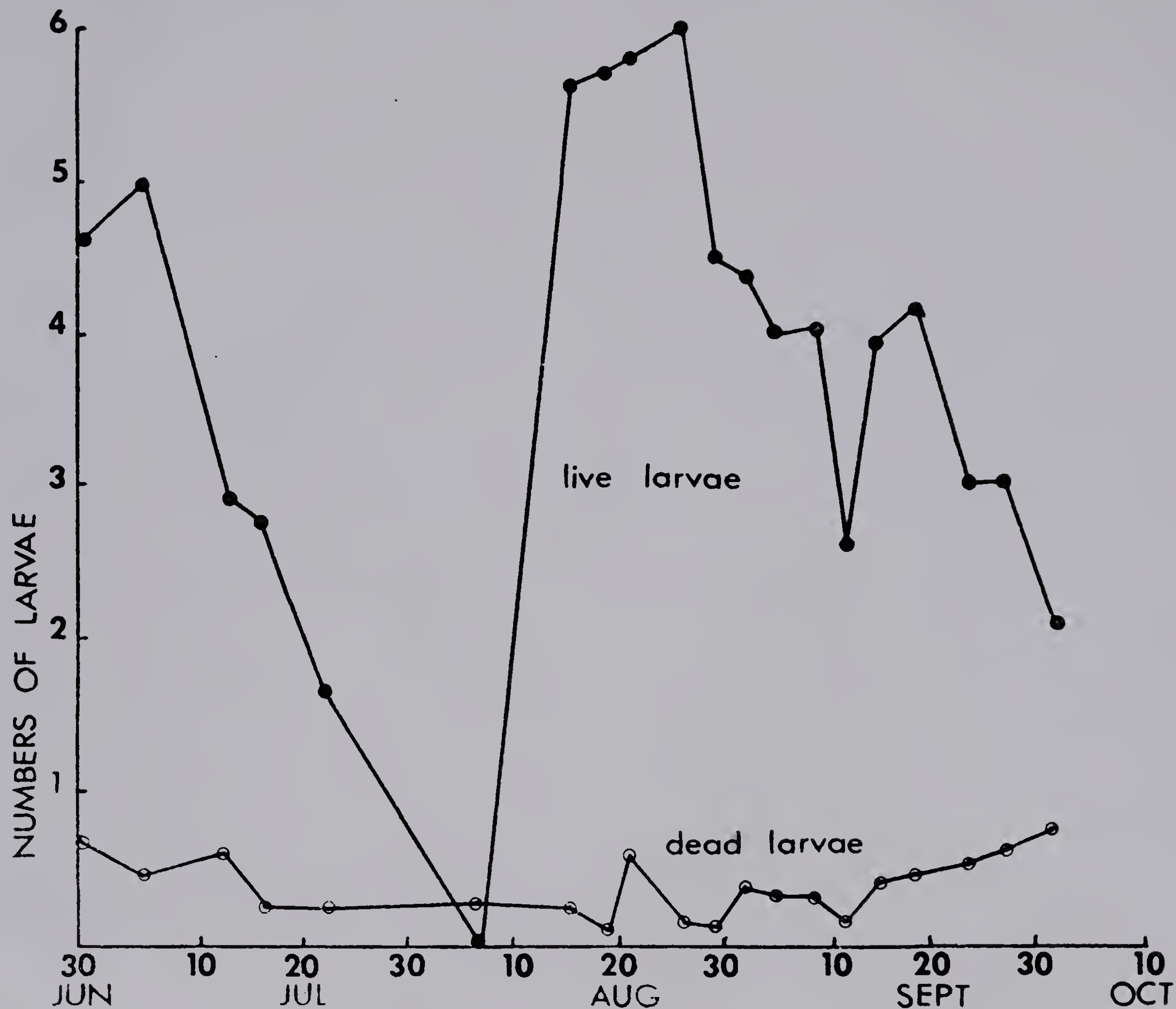

Fig. 31. Mean numbers of G. syringella larvae per mine collected during 1964